ASSESSMENT OF THE IMPACTS OF CLIMATE CHANGE ON EROSION AND WATER RESOURCES: THE CASE STUDY OF UPPER CAU RIVER BASIN, VIETNAM

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MASTER OF SCIENCE
IN
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ABSTRACT

The Upper Cau river basin restricted at Gia Bay station belongs to Cau river basin which plays a significant socio-economic role in the north of Vietnam. It is facing problems in water resources generally, flow particularly and has the possibility of having erosion, especially under the impacts of climate change. The results of the study revealed that the total annual runoff and soil loss at Gia Bay station tends to increase compared to the base period 1980-1999 under the climate change scenario B2. For flow, the changes rate of the later periods is bigger than the previous ones, appropriate with the changing tendency of evaporation and rainfall which are the most important factors affecting on flow regime that later influences on soil erosion. The imbalance in the flow distribution in year is shown in the considerably increasing trend of flow in flood season and decreasing trend in dry season. For erosion, in the entire basin, it was not so severe in the base period. However, the potential erosion of the basin in the future has the increasing trend with more annual soil loss. The flood-season soil loss increases while the dry-season one decreases in climate change scenario B2. The effect of climate change on soil erosion is also not homogeneous throughout the basin. Therefore, under the climate change scenario B2, the climate trends in Upper Cau river basin are leading to severer conditions for runoff generation as well as erosion status due to an increase in evaporation and rainfall in the period of 2020-2100.

Keywords: Flow/Runoff/Erosion/Soil loss/Climate change

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LIST OF ABBREVIATIONS

CC	Climate Change
DEM	Digital Elevation Model
GIS	Geographic Information Systems
HMDC	Hydro-Meteorological Data Center
IPCC	Inter-governmental Panel on Climate Change
MONRE	Vietnam Ministry of Natural resources and Environment
MUSLE	Modified Universal Soil Loss Equation
RS	Remote sensing
SWAT	Soil and Water Assessment Tool

CHAPTER 1

INTRODUCTION

1.1 Background

Vietnam is a country forecasted to be heavily affected by climate change (CC). These days, water resources in Vietnam have been degrading increasingly and seriously due to increasing population and especially under these environmental stresses. Geographical features of the country with extending in the longitude direction and heavily dissected terrain make a direct impact on the monsoon regime, causing unequal distribution on spatial and temporal scales in water resources. Every year, water amount concentrates during 3 or 4 months in rainy season accounting for 70-75%, only in a peak-value month can account for 30%. While during the dry season, water amount accounts for only 25-30%. The uneven distribution is the cause of many kinds of natural disasters which are often threats to production and life of the people in the country.

Vietnam has 2,360 rivers having the length of more than 10 km. There are 9 major river systems with the areas of over 10,000 km^2 including Hong-Thai Binh river basin. And Cau river basin which has a significant socio-economic role in the North of Vietnam is one of its sub-basins. The Upper Cau river basin restricted at Gia Bay station with the total area of 2,835 km^2 is located in Bac Kan and Thai Nguyen provinces which have long historical and cultural features. However, it is one of three critical ones facing problems in water resources that lead to the establishment of the River Basin Commissions. It is at risk of degradation and depletion of quality as well as quantity especially in the context of CC, while the water demand for socio - economic development of the provinces in the basin is increasing rapidly. The average annual ensured water amount level on Upper Cau river basin is about 116x103 m^3/km^2 and 2,250m^3/person/year, much less than that of the whole country

(2,500x103 m^3/km^2 and 10,800m^3/person/year). Due to uneven flow distribution, in the dry-season, water shortage of about 30,106 m^3 for industry and agriculture has been occurred in some areas in Thai Nguyen, especially in January, February, March. At the present, in those months, the river discharge has decreased to 1/3 compared to the dry season of the last 10 years (18m^3/sec to 6 m^3/sec, at Thai Nguyen station) (CRC&PC, 2005). This would make the water shortage certainly much more serious, especially in dry season if there are not effective solutions for exploitation and protection of Upper Cau river basin water resources.

Furthermore, water-induced soil erosion threatens our ability as humans to sustain the population with food and fiber, and is closely linked to economic vitality, environmental quality, and human health concerns. Erosion results in the degradation of a soil's productivity in a number of ways: it reduces the efficiency of plant nutrient use, damages seedlings, decreases plants' rooting depth, reduces the soil's water-holding capacity, decreases its permeability, increases runoff, and reduces its infiltration rate. The sediment deposited by erosive water can bury seedlings and cause the formation of surface crusts that impede seedling emergence, which will decrease the annual crop yields. Meanwhile, Upper Cau river basin has the land suitable for the originally long-developed agriculture: fruit tree and industrial crop in mountainous and hilly areas (GCP–FAO, 2011). Due to territory characteristics, the basin consists of interspersed and scattered hills and valleys, fragmented terrain, elevation differences, steep slope that lead to strong erosion which affects on the agriculture of the basin, for example, in Vo Nhai district in Thai Nguyen. On a slope $<30^0$, soil erosion starts happening when there is heavy rain. From the slope of 30^0 or more, depending on factors of land, vegetation, rainfall, etc., erosion process would occur strongly or weakly.

Moreover, people have directly affected the erosion process through living activities. Deforestation has indirectly promoted the process of soil erosion. The lost forest areas reveal open spaces without vegetation coverage. As having rain, surface erosion occurs more sharply. On Upper Cau River basin, natural forest is covered by 21% of total basin land in the Northern and North-East part and poor forest covers 51% of total land. Therefore, the primary forest has been replaced in part by degraded, second growth forest with the natural rate of deforestation annually of

1%/year. In Bac Kan town (MARD & JICA, 2012), the terrain is mostly hilly with relatively large slope. A few decades ago, the primary forest in the area has been lost due to deforestation for cultivation. Rapidly degraded soils due to leaching and erosion by rain, vegetation constantly trespassed by shifting cultivation and grazing. Statistic figures of Bac Kan and Thai Nguyen (CRC&PC, 2005) show that in the period of 1986-1993, the annual average forestry exploitation productivity is 65,000 m^3 of logs, 723,000 ton of roots, 7,800 ton pulp (for paper production). Natural forest in the area decreased by 1.4 million ha, correspondent with timber volume decreased 1.4 million m^3, very little remaining about 3.9 million m^3. Coverage ratio in Thai Nguyen and Bac Kan reduced from 48% to 39% (in 2000), including new plantations. Although in recent years, land and forest allocation guidelines for people to manage obtained results, but the bare land areas are still a lot. In Bac Kan and Thai Nguyen the remainder is 260.000ha. In the upstream forest of Upper Cau River, Con river where originates water sources, there are only more than 34.000ha shrubs and grasses and more than 200.000 sparse bamboo forest. Shifting cultivation on steep slopes combined with nomadic habit are also the factors that increase soil erosion. The combined effects of soil degradation and poor plant growth often result in even greater erosion later on. Obviously, unreasonable farming practices cause large harm, negatively affect the process of soil erosion on Upper Cau river basin (CRC&PC, 2005). In addition, though mining operations in two provinces of Upper Cau river basin are in the different scales and levels by different forms of production, it is asserted that the environment has been destroyed, increasingly seriously polluted. Thousands of hectares of forest and surrounding areas have been affected by trees, timber exploit and mining activities. In some mines in Bac Kan, Thai Nguyen such as Cho Dien zinc, Khanh Hoa coal, Nui Hong coal, Phan Me Coal, Trai Cau iron..., the protection forest belt have been turning into the landfill, undermined, eroded soil. Those activities of human on Upper Cau river basin greatly affected the ecological environment, soil erosion, degradation, water depletion and more intense flooding.

Additionally, under the context of CC, the number of flash floods occurring recently in the basin has been increasing. The mountainous territory of the upstream areas in the basin has made the consequence of flash floods much more complicated and soil erosion situation worse. Some typical flash floods occurred in the basin such as in Rang river in 1973, Bac Kan in 2000 and in Thai Nguyen, Bac Kan in 2001 (CRC&PC, 2005). In addition, high rainfall events in combination with less permeable soil formations caused significant runoff and subsequently high soil losses and sediment yield on Upper Cau river basin (Binh et al., 2010).

Therefore, Upper Cau river basin is selected as the object of the research. From the results of the study, with successful application of the model, it will be a powerful tool to help managers in managing the basins. The benefits of the model include a more specific orientation, higher efficiency in planning of sustainable development for the basin, better disaster prevention and environmental protection.

Table 1.1 Statistics of two provinces in 2014

Province	**Bac Kan**	**Thai Nguyen**
Area (ha)	486,800.4	354,600.6
Natural forest area (ha)	462,892.113	102,190

Source Vietnam Government Portal (2014a; 2014b)

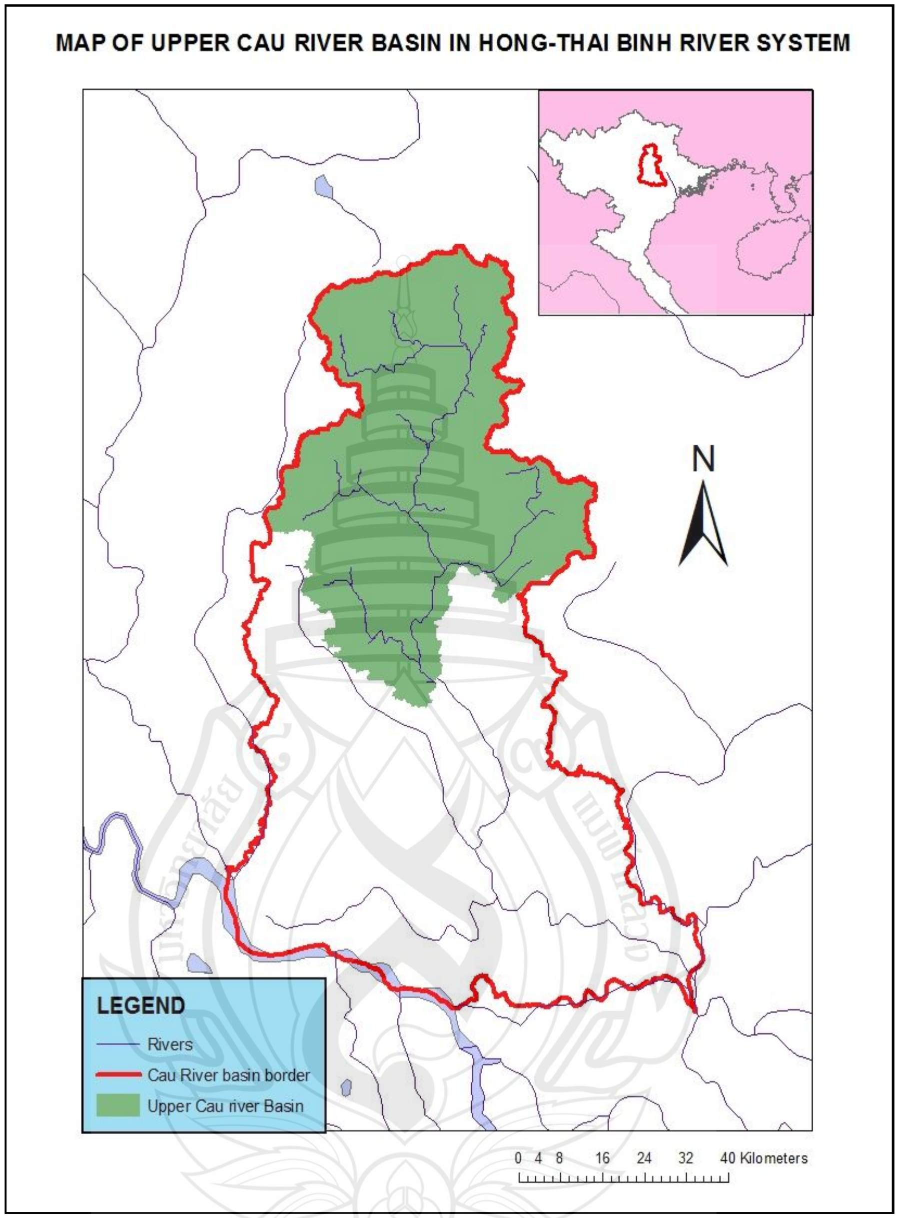


Figure 1.1 Map of Upper Cau river basin in Hong-Thai Binh river system

1.2 Research Questions

1.2.1 General Questions

What are the CC impacts on flow regime and soil erosion on Upper Cau river basin?

What would be the policy management based on the results on Upper Cau river basin?

1.2.2 Specific Questions

How would the annual, flood-season, dry-season flow and soil loss change over time under CC scenario B2 at Gia Bay station?

How were the annual, flood-season, dry-season soil loss distributed in sub-basins in base period of 1980-1999?

How would the annual, flood-season, dry-season soil loss be distributed in sub-basins in the future under CC scenario B2?

What was the erosion status classification in base period of 1980-1999?

What are the policy management based on the results on Upper Cau river basin?

1.3 Objectives

1.3.1 General Objectives

The objectives of the study are to give the quantitative assessment of the changes of the surface water flow and the level of erosion of Upper Cau river basin under the impacts of CC. Thereby, some policy management based on the results could be proposed for the study area.

1.3.2 Specific Objectives

To assess and analyze impacts of CC on the annual, flood-season, dry-season flow and soil loss; on the level and distribution of erosion on Upper Cau river basin.

To propose policy management based on the results on Upper Cau river basin.

1.4 Expected Outputs and Outcomes

1.4.1 Outputs

Annual, flood-season, dry-season average flow at Gia bay station by periods (1980-1999, 2020-2039, 2040-2059, 2060-2079, 2080-2099) (Tables – units: m3/s).

The changes of annual, flood-season, dry-season average flow by periods of the future under the CC scenario B2 at Gia Bay station (Tables, Charts – units: m^3/s, %).

Annual, flood-season, dry-season average soil loss at Gia bay station by periods (1980-1999, 2020-2039, 2040-2059, 2060-2079, 2080-2099) (Tables – units: tons).

The changes of annual, flood-season, dry-season average soil loss by periods of the future under the CC scenario B2 at Gia Bay station (Tables, Charts – units: tons, %).

Annual, flood-season, dry-season soil loss distribution in sub-basins on Upper Cau river basin by periods (Figures – units: tons/ha/year).

Percentage rate of flood-season and dry-season soil loss in the future compared to base period (Figures – units: %).

Erosion status classification in levels in base period (1980-1999) (Table).

1.4.2 Outcomes

Some suggested policy management for sustainable soil and water resources protection and use in order to mitigate damage of flood and drought in the study area in the context of CC will be proposed.

1.5 Scope and Limitations

Due to the limitation of funds, scope of the research, expertise, time, the availability of the data, the thesis would not carry out analysis on water quality (such as COD, BOD, etc) since it would be needed to conduct lots of measuring and surveying processes but study on sediment yield (soil loss) which is representative for erosion process. Moreover, there might have some limit in uncertainty of the CC scenario B2. Also, in this study, one of the limitations is for the future period. The data of rainfall and temperature are compared with the base line and varied across the time according to the scenario B2 projected by Vietnam Ministry of Natural resources and Environment (MONRE). However, for the simplicity of the analysis and the availability of the data, the land use land cover map is fixed in 1993.

1.6 Conceptual Framework

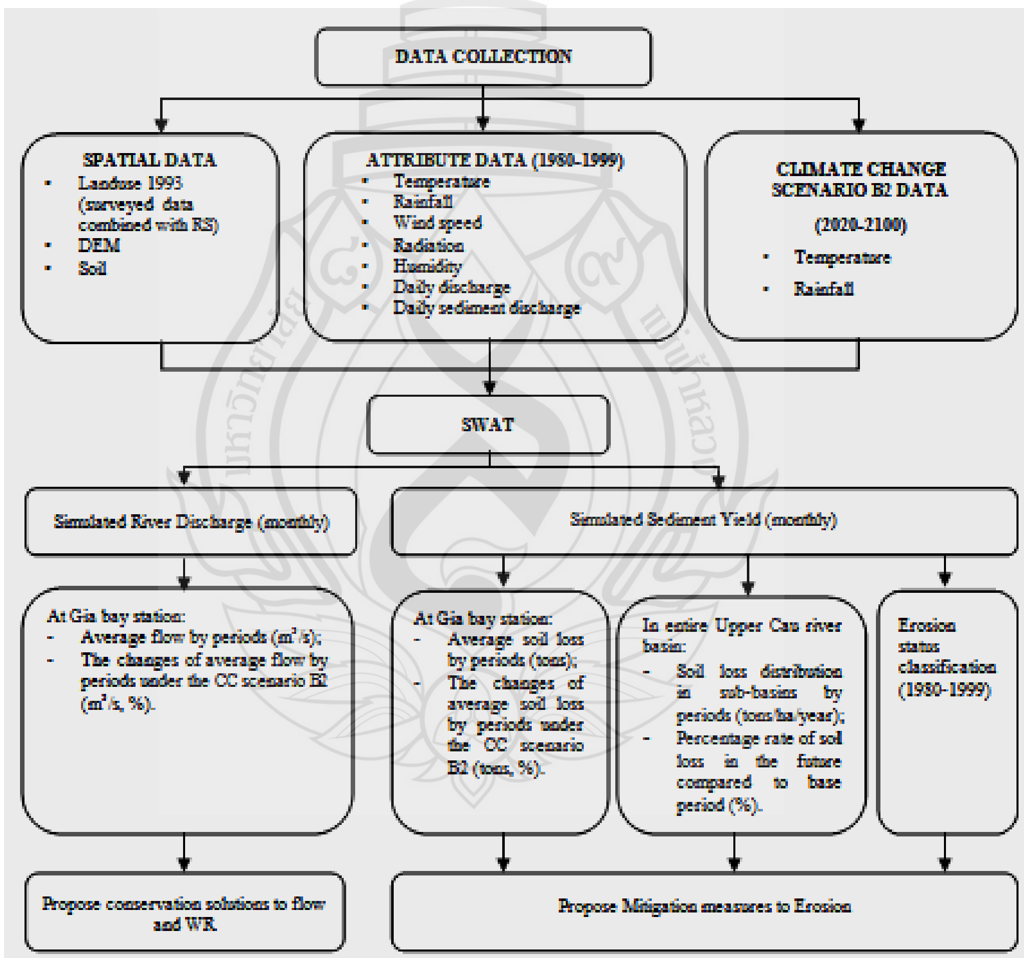


Figure 1.2 Conceptual framework

CHAPTER 2

LITERATURE REVIEW

2.1 Previous Related Literature All Over the World

Changes in climate have been observed in the past decades, and more changes have been projected for the coming decades. In many countries, governments are seeking advice from a wide range of disciplines on the potential impacts of CC on the environment and their society and economy (Feenstra, Burton, Smith & Tol, 1998). CC impact assessment studies are concerned with the estimations of what might happen under specified CC scenarios and with the comparison of the results of these scenarios with conditions that might be expected in the absence of CC.

Literature on CC impacts has grown considerably in many areas such as ecological systems and human systems (Aspinall & Matthews, 1994; Huynen, Martens & Akin, 2013). Also, Global warming is likely to have significant impacts on the hydrologic cycle, affecting water resources systems (Arnell, 2004). The increasing amount of papers published in several key journals illustrates that the focus and interest are drawn to the study of effects of CC on hydrological regimes and water resources. There was variety of those studies, such as Beare and Heaney (2002); McBean and Motiee (2008); etc. In California, since 1983, more than 60 studies have investigated CC impacts on hydrology and water resources such as Miller, Bashford and Strem (2003); Dettinger, Cayan, Meyer and Jeton (2004); Van, Wood, Palmer and Lettenmaier (2004); etc.

Also relating to water resources, soil erosion is the single most important environmental degradation problem in the world. Negative impacts of technical change, inappropriate government policies and poor institutions are largely responsible for the continued soil erosion (Ananda & Herath, 2003). Further, nowadays, CC has been contributing to the problem much more serious. The process involved in the impact of CC on soil erosion by water are complex, involving changes in rainfall amounts and intensities, number of days of precipitation, ratio of rain to snow, plant biomass production, plant residue decomposition rates, microbial activity, evapo-transpiration rates, and shifts in land use necessary to accommodate a new climatic regime. Several studies about this issue are Walling and Webb (1996); DaMing, Jing, KaiDao and YunGang (2007); etc.

2.2 Previous Related Literature on Modelling

In recent years, application of models has become an indispensable tool for the understanding of the natural processes. The changes of climatic variables had been used to assess changes in natural runoff using different types of hydrologic or mathematical models (e.g. statistical or physically based). For example, Vicuna (2005) estimated the impacts of CC on California water resources using CalSim-II; Hailemariam (1999) investigated the sensitivity of water resources to CC in the Awash River Basin in Ethiopia and used the IIASA integrated water balance model to estimate runoff under a changed climate. Overall, the application of the distributed-parameter models to calculate the flow in the basins is necessary in order to have clear directions for catchment integrated planning.

Likewise, the common trend these days in erosion research is towards modelling describing the dynamics of erosion process and erosion research in combination with other sciences, mostly to study the process as well as impact of erosion on the environment in order to get the feasible anti-erosion measures. There are some soil erosion models used such as (1) RUSLE (Revised Universal Soil Loss Equation) – a kind of empirical and statistics formulas (Renard, Foster, Weesies, McCool & Yoder, 1997); (2) association models: AGNPS (Agricultural nonpoint source pollution model), SWAT (Soil and Water Assessment Tool) (Arnold, Srinivansa, Muttiah & Williams, 1998) and MMF (Morgan/Morgan/Finney) (Morgan, 2001); (3) processing physical-based models: EUROSEM (Morgan et al., 1998), WEPP (Water erosion prediction project) (Flanagan, Ascough II, Nearing & Laflen, 2001) for calculating flow and sediment on steep slopes, CREAMS (Chemicals, runoff and erosion from agricultural management systems), LISEM (Limburg Soil Erosion Model) and KINEROS (Kinematic runoff and erosion model). Each model has its own advantages and disadvantages in calculating the amount of eroded soil.

Dominantly, SWAT (Soil and Water Assessment Tools) model is one of the most widely used watershed-scale simulation tools and bringing the most effective results when studying in soil erosion and water resources. There are many advantages of SWAT such as it has been used around the world to address watershed questions and help in watershed management and has been used in hundreds of scientific studies that have been published in peer-reviewed journal arcticles leading its scientific acceptance as well as established.

SWAT uses Modified Universal Soil Loss Equation (MUSLE) which was developed on the basis of the USLE equation (Williams, 1975) to estimate soil erosion and sediment caused by rainfall and runoff. USLE meets the requirements set out by the study of soil erosion assessment. On the other hand, USLE model refers to factors affecting erosion separately but still in a close relationship.

The first version of SWAT was developed in the early 1990s and released as version 94.2. Engel, Srinivasan, Arnold, Rewerts and Brown (1993) reported the first application of SWAT in the peer-reviewed literature; Srinivasan and Arnold (1994) and Arnold et al. (1998) later published the first peer-reviewed description of a geographic information system (GIS) interface for SWAT and overview describing the key components of SWAT, respectively. Arnold and Forher (2005) described the expanding global use of SWAT as well as several subsequent releases of the model: versions 96.1, 98.2, 99.2, and 2000. Gassman, Reyes, Green and Arnold (2007) provided further description of SWAT, including SWAT version 2005, and presented an in-depth overview of over 250 SWAT-related applications that were performed worldwide. Krysanova and Arnold (2008), Douglas-Mankin, Srinivasan and Arnold (2010), Tuppad, Douglas-Mankin, Lee, Srinivasan and Arnold (2011) provided further updates on SWAT application and development trends, and the latter two articles provided further description of SWAT version 2009. It has been employed widely to evaluate the impact of CC on soil erosion and sediment flux. Li, Chen, Wang and Peng (2011) applied SWAT to evaluate the effect of temperature change on water discharge, and sediment and nutrient loading in the Lower Pearl River basin, China. Hanratty and Stefan (1998) have also described the application of SWAT to evaluate the impact of CC on sediments in an agricultural watershed in Minnesota and in five European catchments. Due to the spatial and temporal heterogeneity in soils properties, vegetation and land use practices, a hydrological cycle is a complex system.

Although SWAT still has some disadvantages in calibration and uncertainty analysis, or so many parameters making difficult in model running, it was selected because of ability to characterize complex watershed representations to explicitly account for spatial variability of soils, rainfall distribution, and vegetation heterogeneity. With the distributed-parameter models and water balance models like SWAT, it is the efficient model in the problems of water resources management in the basin scale. The problem identifies the hydrological consequences caused by changes in rainfall, temperature and other meteorological factors or calculates the responses of spatial changes of the hydrological factors. It would have high accuracy, flexibility and ease of use. In summary, it is needed to use a physically-based distributed model in order to assess the spatial distribution of water resources and sedimentation.

2.3 Previous Related Literature in Vietnam

In Vietnam, water resources with their unequal distribution on spatial as well as temporal scales and abundant feature is a hot issue that drawn a lot of concerns from scientists. These days, water resources tend to be degraded by the effects of global CC and unsustainable exploitation and use. In many universities, institutions, organizations, there are series of studies implemented on water resources in many river basins and specific provinces of Vietnam aiming to contribute to the government’s planning and river basin management. Aspects of water resources such as quantity and quality have been mentioned. Son, Tuan, Hang and Nhu (2011) analyzed the changes of water resources on Nhue-Day river basin under the impacts of CC, while Nhu (2011) focused on the extreme of the flow in the same study area. However, they only used the future scenarios of 2020, 2050 compared to the baseline period of 1970-1999. Using SWAT model and GIS, Liem, Hong, Minh and Loi

(2011) had a study on assessing water discharge in Be river basin, Vietnam. Water discharge is an important hydrological parameter that defines the shapes, size and course of the stream. It's useful information for understanding more deeply about water resources. The study focused to quantify the impact of topographic, land use, soil and climatic condition on water discharge. SWAT in combination with GIS has identified clearly the objectives of the study with the capacity of enhancing the precise of flow simulation results from rainfall and physical characteristics of the basin.

Additionally, a wide range of studies has been conducted on soil erosion issue in many parts of Vietnam using lots of research methods. Taking some examples such as in Son Dong district in Bac Giang province (Ha, 2009); Vo Nhai district in Thai Nguyen province; Da Tam watershed in Lam Dong province (Tu, Liem, Minh & Loi 2011); Tam Nong Commune in Phu Tho province (Thang, 2010); Tay Nguyen region; Son La province; Dong Nai river basin, etc. Binh, Tuan and Huong (2010) used modelling and web technologies to assess the level of soil erosion in northwestern region of Vietnam in general. In Dakrong Commune, Quang Tri province, Trong, Viet and Huong (2012) used RMMF (Revised Morgan-Morgan-Finney) model to find out the soil erosion possibility.

For soil erosion and water resources assessment, SWAT model has still been proved to be an effective tool. Utilizing USLE, for instance, Chau and Tuan (2011) implemented a study about soil erosion management in Hue province. A little bit beyond the country border, Rossi et al. (2009) evaluated in hydrologic perspective the lower Mekong river basin. All studies show the effectiveness of ustilizing SWAT when it can model and combine many physical processes in one basin. Taking into account CC, the study of Phan, Wu and Hsieh (2011a) also used SWAT to assess its impacts on stream discharge and sediment yield in Phu Luong watershed in Northern Viet Nam. Results showed that the stream discharge was likely to increase in the future during the wet season with increasing threats of sedimentation. Conducted by the same authors group with the same model tool, another study of Phan et al. (2011b) implemented in Cau river basin, Vietnam. This study used three CC scenarios B1, B2, and A2 to assess but only showed the seasonal values, not the monthly though CC is needed to express the extent of more details. Additionally, the study just gave the comparison of stream discharge and sediment load change between only 3 decades of 2020s, 2030s, 2050s with the baseline period. To satisfy those deficiencies in Phan's research, the thesis would use the data from the future from 2020 up to 2100 – a long enough period – focusing fundamentally on just one scenario B2 to perform the changes of stream discharge and sediment yield of the Upper Cau river basin and go into details in each month and season in year. Furthermore, the output of Phan's study just stopped at changes of sediment yield without describing the process of surface erosion with its levels which could have been shown apparently in maps. The thesis would fill with it.

Moreover, the method of applying Geographic Information Systems (GIS) and remote sensing (RS) images has the capability to analyze the space in a short time. On the basis of using RS data and RUSLE, Ty (2008) focused on simulation of soil erosion risk of mountainous landscape. The thesis would also like to combine results from RS with surveyed Land use map to make it more accurate thereby create more precise inputs for SWAT model.

In conclusion, many studies and researches have improved that the significance of researches in water resources and soil erosion issues in Vietnam particularly and the world generally, especially in the context of CC. Mathematic models and geospatial analyses tools like SWAT has been proved to be very useful for studying hydrological processes and hydrological responses to CC. Therefore, by using SWAT, the thesis would like to improve understanding of the potential impacts of CC on these issues in one of the most important basins in Vietnam – Upper Cau river basin.

CHAPTER 3

METHODOLOGY

3.1 Overview of the Study Area

3.1.1 Geographical Location

Cau river basin belongs to Hong-Thai Binh river basin – a large basin in northern part of Vietnam, which has a significant geographic and economic location, rich and diversified natural resources as well as history of socio-economic development. The Upper Cau river basin restricted at Gia Bay station with the total area of 2,835 km^2 is located in Bac Kan and Thai Nguyen provinces. Map of Upper Cau river basin is shown in Figure 3.1.

3.1.2 Topography

Upper Cau river basin is surrounded by Gam river bow in the west and Ngan Son bow in the east. In the north and northwest, there are the mountainous peaks with the height is above 1,000m (Hoa Sen 1,525m, Phia Deng 1,527m, 1,125m Pianon). In eastern, there is Ngan Son bow with mountainous peaks above 700m (Coc Xe 1131m, Lung Giang 785m, Khao Khien 1107m). Generally, Upper Cau river Basin has varied and complex terrain in the direction of northwest - southeast, characterized by two types of mountainous and midland.

The mountains has an average altitude of more than 1000m which are distributed following with the north and northwest watersheds of the basin, often sharp mountain peaks with very steep slopes (up to 40-45^0). Low mountains, medium hills are distributed mainly in the Cho Don, Bac Kan, Dinh Hoa, Thac Buoi, Dai Tu. Low hills are interspersed in the wide valleys, has an average altitude of about 15 - 20 meters with relatively thick weathered layer, located in the valleys of the mountains. Limestone is developed in the northeastern areas of Bac Kan town, central and upstream areas of Cho Chu river and consists of mainly Nghinh Tuong river basin. Karst development is in many complex forms through the ages making cave system at many different altitudes, the karst valleys cleave limestone slopes into ranges with separation levels, on which there are secondary karst types of erosion ditches, sinkholes. In this geomorphology region, there are many underground rivers with caves developed, their direction is usually following that of surface rivers.

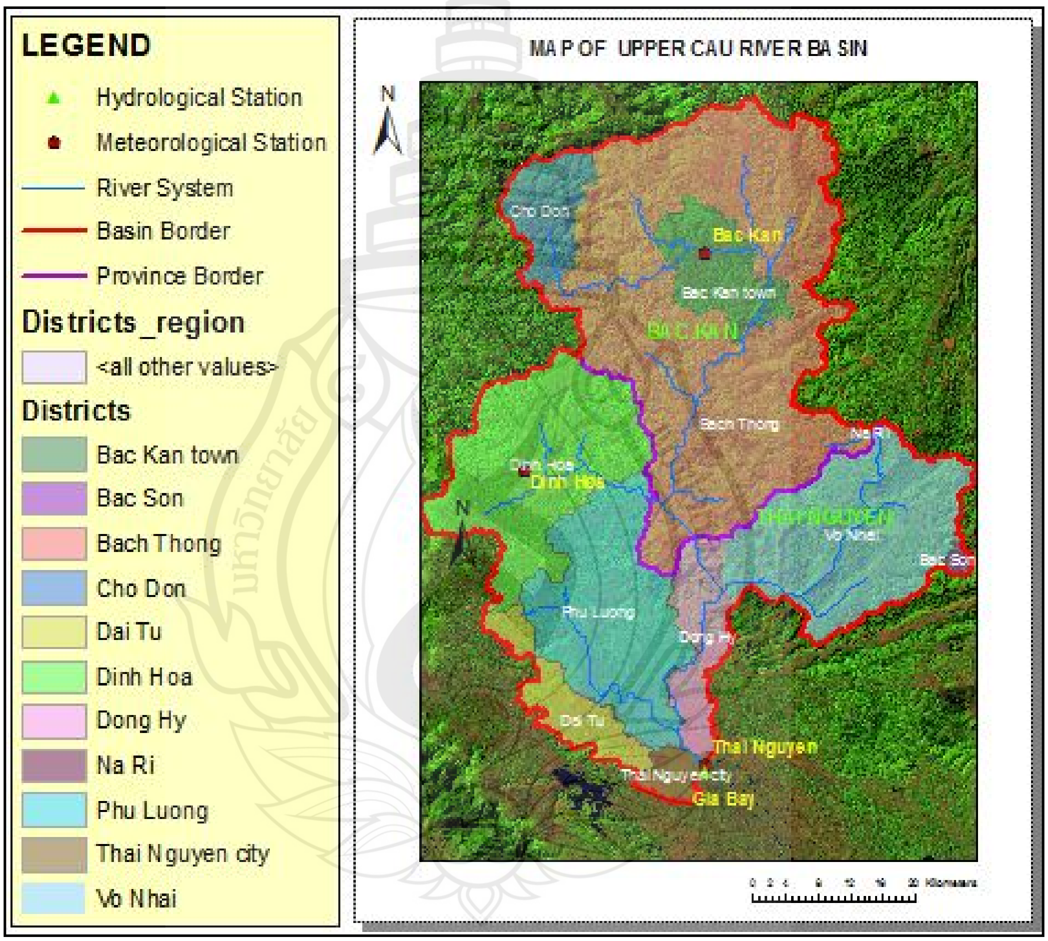


Figure 3.1 Map of Upper Cau river basin

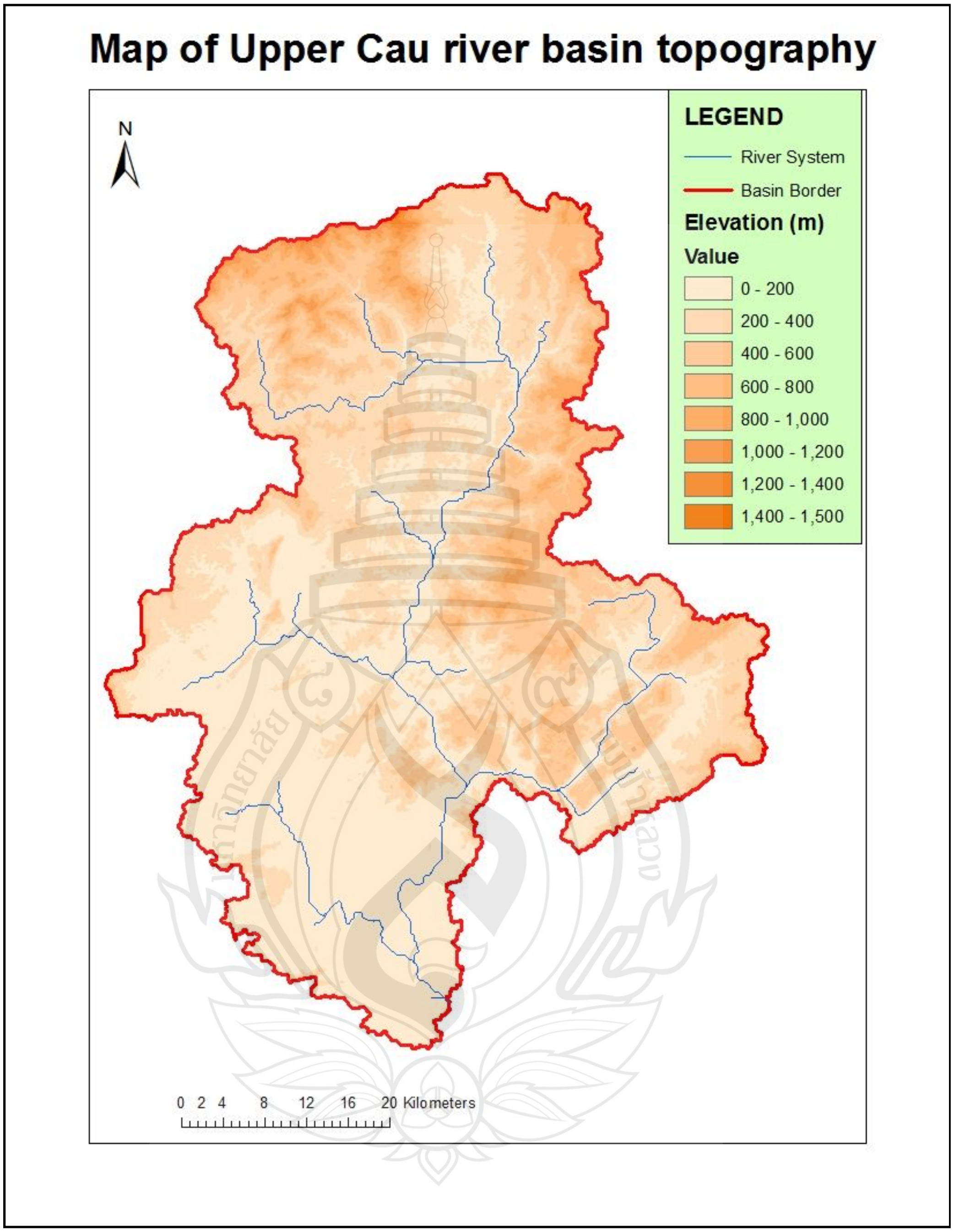


Figure 3.2 Map of Upper Cau river basin topography

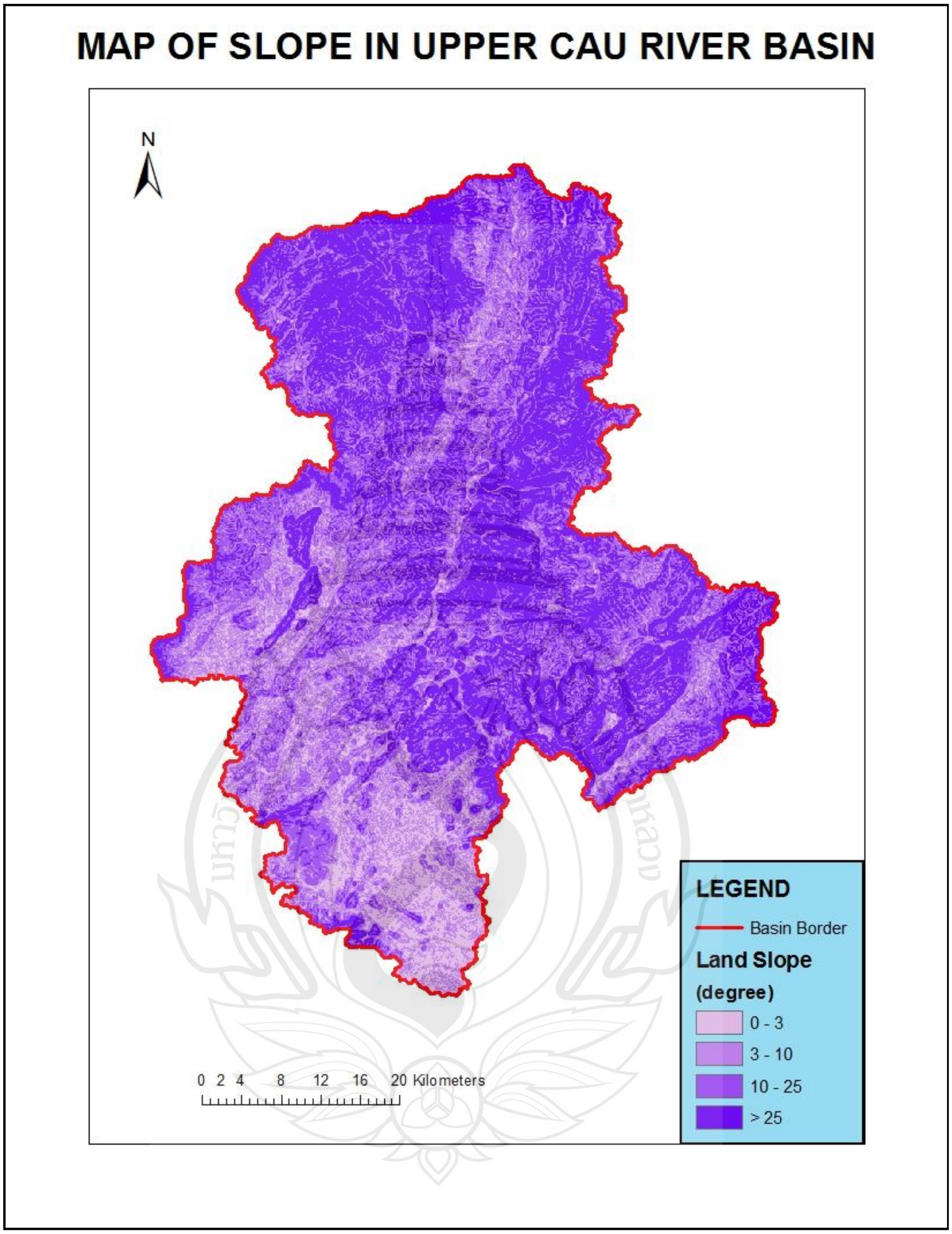


Figure 3.3 Map of Upper Cau river basin slope

3.1.3 Soil

Apart from rock, the Upper Cau river basin has some major soil groups: Rocky- inert erosion soil group: Distributed mainly in 3 districts: Pho Yen, Phu Binh, Dong Hy (Thai Nguyen).

Boggy and slope-convergent soil group: Distributed in some areas of districts: Pho Yen, Phu Binh, Dong Hy, Dinh Hoa (Thai Nguyen) and Bach Thong, Cho Don (Bac Kan).

Yellow red soil group: Distributed mainly in the upstream and middle areas of the basin.

Mountainous red yellow humus soil group: Developed at altitudes above 600m, mainly distributed in districts: Bach Thong, Cho Don (Bac Kan) and Dai Tu (Thai Nguyen).

Map and list of Upper Cau river basin soil types will be shown in Figure 3.4 and Table 3.1.

Table 3.1 List of soil types

No.	Types of Soil	SWAT code
1	Yellow brown soil	FRx
2	Feralit grey soil	ACf
3	Mountainous humus grey soil	ACu
4	Red brown soil	FRr
5	Rock	LPq

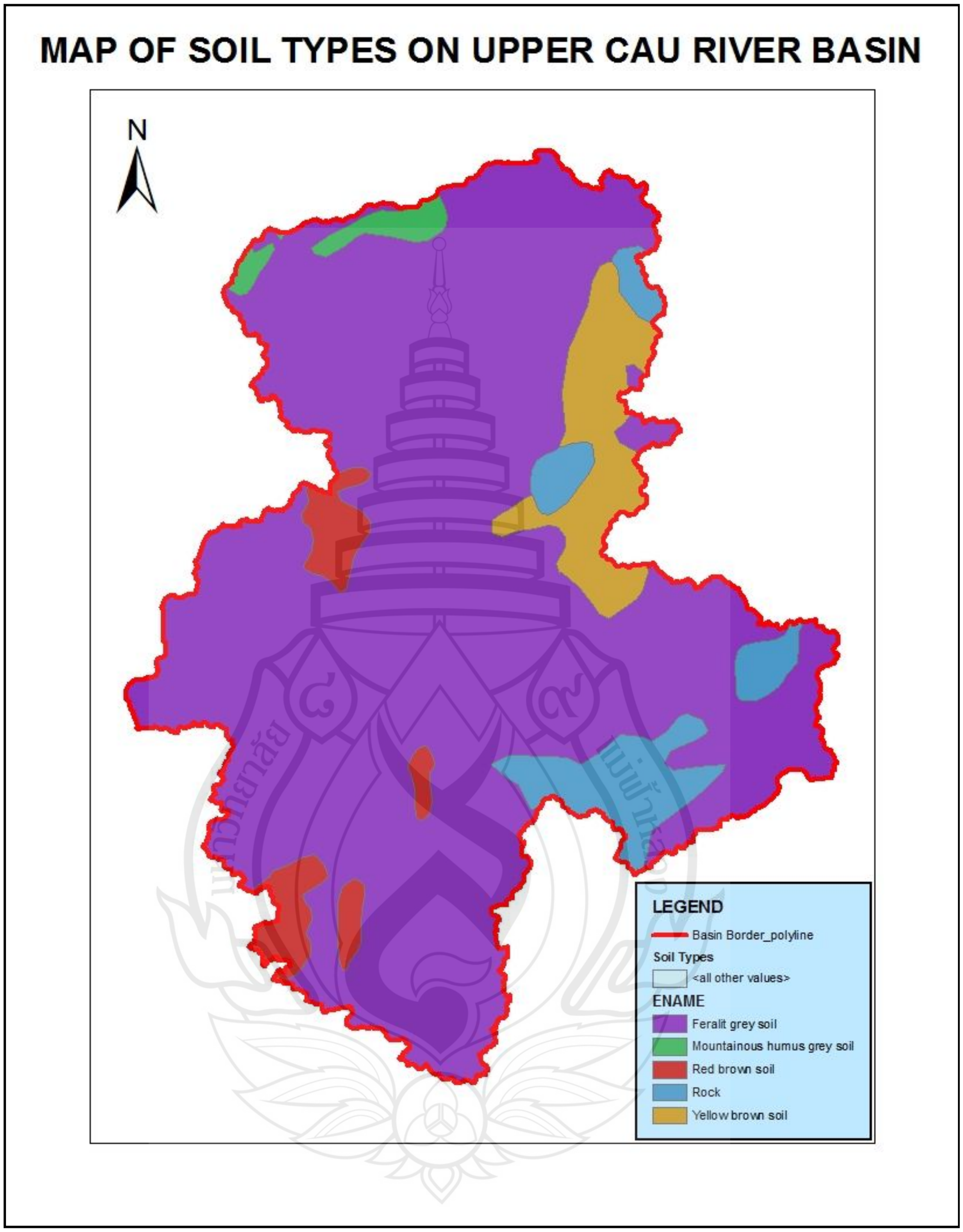


Figure 3.4 Map of Upper Cau river basin soil types

3.1.4 Flora and fauna

In the Upper Cau River basin, the primary forest has been replaced in part by poorly recoverd forest, the natural rate of deforestation annually of 1%/year. Flora has about 1000 species, 500 species of animals, including many species of animals and plants of rare or particularly rare.

The flora and fauna in the basin is rich and diverse. Scientists discovered in Bac Kan, there are 831 high-level plants under 537 lines of descent and 145 descents, of which 250 species of medicinal plants, over 120 species of trees for timber and 52 rare plant species should be protected, 420, 91 lines of descent, 28 sets of 4 classes of animals; Thai Nguyen has 134 plants species belonging to 39 descents, 3 precious wood species, 100 species of medicinal plants, 422 species of animals belonging to 91 descents, 28 sets, 4 classes of animals (birds, mammals, reptiles, amphibians) in which tigers, leopards, bears, wild boars, deer, almost extinct.

3.1.5 Climate Regime

Climate on Upper Cau River basin is elementarily characterized by tropical monsoon climate of northern Vietnam. Abnormally cold winter, little sunshine and much drizzle broke the typical characteristics of tropical climate, however, it has contributed to the diversity of climate, is a prerequisite for the development of a diversified ecosystems that do not exist in tropical or temperate zones typically. The data was collected from the Hydro-Meteorological Data Center (HMDC).

3.1.5.1 Monsoon

The climate in the North of Vietnam in general, Upper Cau river basin in particular belongs to tropical monsoon climate zone. As mentioned above, the climate in a year has two separate seasons: hot, humid, much rain summer; cold, dry and less rain winter.

Table 3.2 Yearly and monthly mean wind speed on Upper Cau river basin (m/s)

No.	Station	Month												Year
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
1	Bac Kan	1.4	1.5	1.3	1.2	1.2	1	0.9	0.8	0.9	1.1	1.4	1.3	1.2
2	Dinh Hoa	1.2	1.3	1.2	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.1	1.2	1.2
3	Thai Nguyen	1.4	1.5	1.5	1.7	1.8	1.5	1.5	1.3	1.3	1.4	1.3	1.5	1.5

The impact of the atmospheric circulation to basin terrain creates its own climate regime for the river basin. Average annual and monthly wind speed of the river basin fluctuate relying on altitude and terrain apparently.

3.1.5.2 Sunshine – Temperature

The basin has average hours number of sunshine in the whole year ranging from 1200h - 1800h/year. The average temperature of the air annually ranged from 18 - 230C. The air temperature measured at a number of stations in the basin is presented in Table 3.3.

Table 3.3 Monthly avarge, maximum, minimum air temperature during observations at the basin stations

No.	Station	Element	1	2	3	4	5	6	7	8	9	10	11	12	Year
		T^{o}C	14.6	16	19.2	21.7	26.1	27.3	27.1	26.7	25.7	22.9	19.1	15.8	21.8
1	Bac Kan	Tmax	30.8	33.2	34.4	37.8	38.8	39.4	37.8	37.4	36.6	34.1	33.6	30.7	39.4
		Tmin	-0.9	3.6	5.3	10.4	15.3	16.5	18.7	19.8	13.7	8.5	4	-1	-1
		T^{o}C	15.1	16.4	19.5	23.3	26.7	27.9	28.1	27.5	26.3	23.6	19.8	16.5	22.6
2	Dinh Hoa	Tmax	31.3	34.6	35.9	35.7	39.6	38.1	37.7	37.8	37	33.9	32.8	30.8	39.6
		Tmin	0.5	3.2	6.5	11.4	16.2	18.3	20.2	20.5	14.8	8.1	4.9	-0.4	-0.4
		T^{o}C	15.6	16.8	19.7	23.5	27	28.4	28.5	27.9	26.9	24.4	20.7	17.4	23.1
3	Thai Nguyen	Tmax	31.1	33.5	35.7	35.2	39.4	39.5	38.8	37.5	36.7	34.9	34	30.6	39.5
		Tmin	3	4.2	6.1	12.9	16.4	19.7	20.5	21.7	16.3	10.2	7.2	3.2	3

3.1.5.3 Air humidity

Average air humidity in many years in areas on the basin ranges from 81-87%, the mountainous areas having many forest trees, much rainfall have higher humidity. The areas having highest humidity are Bac Kan, Dinh Hoa.

Table 3.4 Average relatively air humidity at several observed stations (%)

No.	Station	Month												Year
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
1	Bac Kan	82	82	83	84	83	85	86	87	86	84	83	82	84
2	Dinh Hoa	82	83	85	86	83	84	87	86	86	83	83	81	84
3	Thai Nguyen	80	82	85	86	82	83	83	86	83	80	79	78	82

3.1.5.4 Evaporation

Average evaporation in areas is ranging from 540 - 1000mm depending on terrain locations, specific features of temperature, hours of sunshine. Region having small evaporation is the Cau river upstream. Lower areas have large evaporation is Thai Nguyen.

Table 3.5 Total yearly and monthly average evaporation (measured by Piche tube) (mm)

Station	1	2	3	4	5	6	7	8	9	10	11	12	Year
Bac Kan	55.6	54.8	59.9	63.6	80	98	60.6	58.4	62.8	67.9	61.2	59.9	752.7
Dinh Hoa	52.4	49.7	54.2	60.8	85.5	77.9	78.1	65.9	66.3	68.7	62.4	60.7	782.5
Thai Nguyen	73.8	64	62.8	65.2	97.6	93.8	90.8	77.8	83.9	95.9	88.1	85.2	978.9

3.1.6 Hydrology and Water resources

3.1.6.1 Rivers System

The mainstream of Cau river is derived from Van On mountains at 1,175m height in the Cho Don district, Bac Kan province. Upstream flows of the river has the direction of north - south, the average height of 300 – 400m, narrow and steep river bed, many rapids, large winding step (2.0), the average river width of 50 - 60 m in the dry season, can be up to 80 - 100 m in flood season, the bottom slope of about 10%o. From the middle stream of Cho Moi, the river flows northwest – southeast over a long length then flows from the north - south to Thai Nguyen, extended valley, gradually lower mountains, the average height of about 100 - 200 m, slope bottom fell 0.5%o.

The river bed of the dry season is about 80 - 100m wide, meandering value is large (1.9). Stream and river network is quite developed, network density reaches 0.7 -1.2 km/km^2, the main tributaries evenly distributes along the main line. On the whole basin, there are 2 tributaries of relatively large areas which are Cho Chu, Nghinh Tuong River. The mainstream of Cau river after flowing over rapids in a narrow valley of Bac Kan down to Thai Nguyen, becomes a valley and begins to expand gradually. There are relatively low and old thresholds along the riverbanks and prone to be inundated in heavy flooding, so that the river has dykes from Thai Nguyen to downstream. Map of River system of Upper Cau river basin is shown in Figure 3.5.

Table 3.6 Morphological characteristics of the rivers on Upper Cau river basin

No	River	Length (km)	Area (km^2)	Average height (m)	Average slope (%)	Width (km)	Coefficient of water concentration	Winding coefficient	River network density
1	Cau	288.5	6030	190	16.1	31	2.1	2.02	0.95
2	Cho Chu	36.5	437	206	24.6	11.6	1.4	1.4	1.19
3	Nghinh Tuong	46	465	290	39.4	12.9	1.5	1.6	1.05
4	Du	44	360	129	13.3	10	1.7	1.4	0.94

Source Xuan (2007)

3.1.6.2 Surface water resources

1. Rainfall

On the basis of observation documents of the basin stations, it is found that the annual average rainfall is not very big, ranging from 1500 - 2000mm. The data is shown in Table 3.7 and Figure 3.6.

Table 3.7 Yearly and monthly average rainfall (mm)

No.	Station	1	2	3	4	5	6	7	8	9	10	11	12	Year
1	Bac Kan	22.5	30.0	55.5	110.1	176.5	263.3	280.5	290.5	158.5	83.2	43.6	18.6	1533
2	Dinh Hoa	22.2	29.7	54.0	106.3	210.5	277.5	332.5	320.4	185.1	108.4	43.1	17.3	1707
3	Thai Nguyen	26.7	34.6	61.5	121.3	237.3	335.7	423.9	360.6	248.7	146.4	52.3	25.3	2074

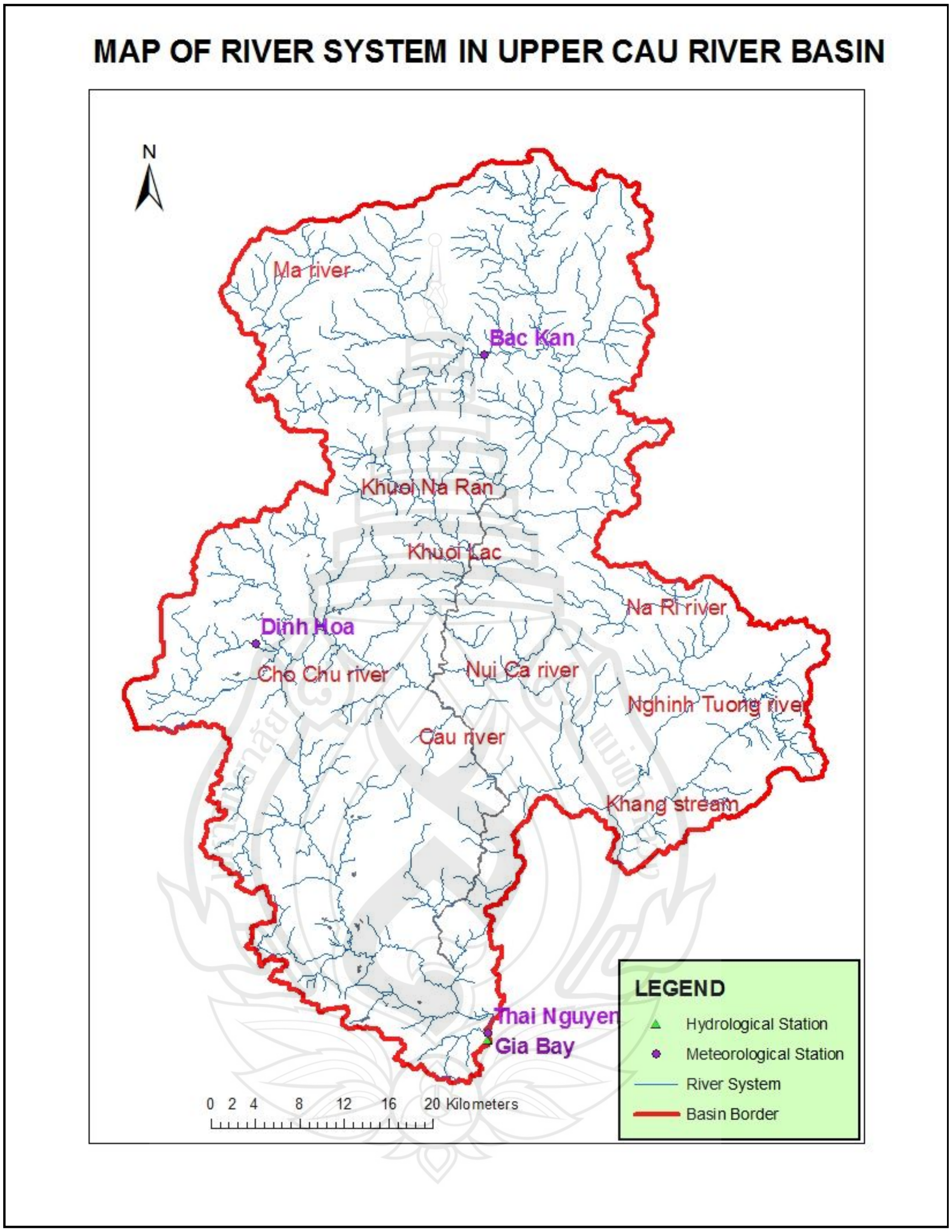


Figure 3.5 River System of Upper Cau river basin

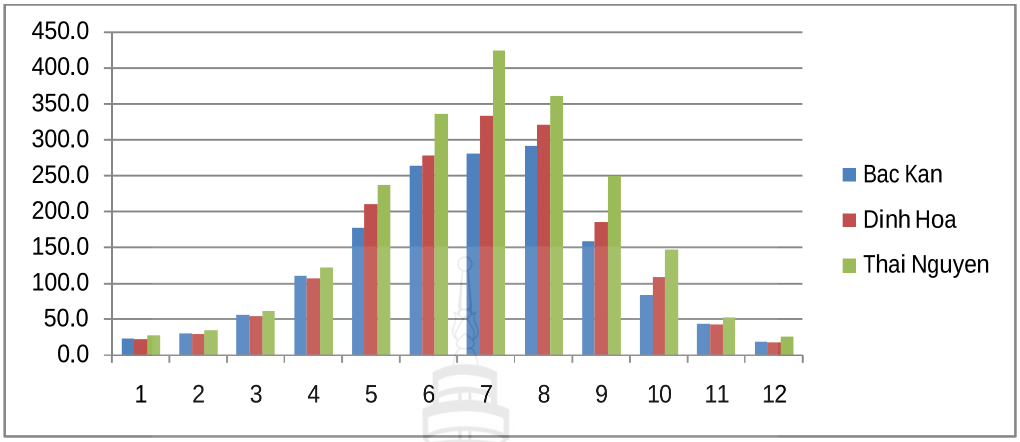


Figure 3.6 Monthly rainfall distribution at stations on Upper Cau river basin

Rainy season on Upper Cau river basin lasts from May to October, while dry season lasts from November to April of the following year. In rainy season, rainfall accounted for 75-80% of the total annual rainfall, months with the heaviest precipitation are July and August with rainfall distributed over 300mm/month. Dry season has rainfall which accounts for 20-25% of the total annual rainfall. The months having the least rainfall are December and January. Rainfall is unevenly distributed and depends on the topography of each region.

2. Runoff

Due to unevenly rainfall distribution, according to flow regime, there are two seasons in a year: flood season and dry season. Flood season is from June to October and accounts for 70-80% of total annual flow. Dry season lasts 7-8 months, from November to May next year and accounts for only 20-30% of total annual flow. The three exhausted months are January, Februay and March, accounts for 5.6 to 7.8% of total annual flow. In recent years, due to upstream forest has been cut down, the flow in those areas has the trendency of depletion, some areas are desertized.

3.1.6.3 Ground water resources

The groundwater source on Upper Cau river basin is not rich and the groundwater amount exploited for daily life and production of local people is not much. The total potential exploitable reserve in Thai Nguyen is approximately 4.1

million m^3/day while Bac Kan province accounting for only about 7.69 thousand m^3/day.

3.1.6.4 Water resources quality

Upper Cau river basin receives wastewater from 2 provinces Bac Kan and Thai Nguyen. Water quality now is affected by agricultural activities, industrial activities, mining, etc of these provinces. The water quality of Cau river in most of local areas is unsatisfactory for domestic purposes. The upstream of Cau river located in Bac Kan province, apart from the Cau River mainstream, there is also Cho Chu tributary river. The water quality of the two rivers is relatively stable.

3.1.6.5 Meteorological and Hydrological stations

On Upper Cau river basin, the meteorological stations are located in towns, cities and established from the decades of 1920s, 1930s. The meteorological elements sush as radiation, sunshine, temperature, humidity, air, wind, etc are observed there. The hydrological station observes adequate elements on the main stream. This study uses data from 3 meteorological stations and 1 hydrological station on Upper Cau river basin (Table 3.8).

Table 3.8 List of stations used on Upper Cau river basin

No.	Type	Station	Longitude	Latitude
1	Hydrological	Gia Bay	105.83	21.58
2	Meteorological	Dinh Hoa	105.63	21.92
3		Thai Nguyen	105.83	21.60
4		Bac Kan	105.83	22.15

3.2 Climate Change Scenarios for Upper Cau river basin

CC, according to Inter-governmental Panel on Climate Change (IPCC) usage, refers to change in climate state identified through its changes in the average value or the feature taking place in a decades-long period or more. It refers to any change in climate over time whether due to natural variability or as a result of human activities.

In a CC impact assessment, climate scenarios are used to provide quantitative assessments of climate impacts. According to IPCC, a CC scenario is a plausible description of future climate, based on a set of climatic relations, being developed to be used in studies of the consequences of CC induced by anthropogenic activities and often used as inputs for impact assessment. The IPCC's results are presented in the first assessment report in 1992 through the fourth assessment report in 2007.

In 2007, the IPCC published a series of scenarios ranging from "business as usual/no actions taken" to "aggressive actions taken" to reduce CC. Models based on these scenarios from the IPCC 2007 report predict that average global surface temperatures will likely rise by an additional 2 to 11.5 degrees F (1.1 to 6.4 degrees C) above the 1980s-1990s average by 2100. This temperature increase will be accompanied by other environmental changes such as an increase in global sea level up to two feet or more.

Based on IPCC publishment, MONRE's reports (2009, 2012) stated scenarios of greenhouse gas emissions and chose to calculate and develop climate scenarios for Vietnam's 7 regions are: low emission scenario (B1), intermediate emission scenario of the medium scenario group (B2) and intermediate emission scenario of the high emissions scenario group (A2). The factors considered in the scenarios include: increase in temperature; changes in seasonal and annual mean rainfall; climate extremes (mean maximum, minimum daily temperatures, number of days with temperature higher than 35^{o}C, and changes in maximum daily rainfall); sea level rise at coastal regions.

With the natural conditions, socio-economic status, population and level of interest on Upper Cau river basin's environment, in this study, the intermediate emission scenario of the medium scenario group (B2) was selected to assess the impact of CC on water resources and erosion. B2 family: Continuously increasing population, but at a rate lower than A2; the emphasis is on local rather than global solutions to economic, social and environmental sustainability; intermediate levels of economic development; less rapid and more diverse technological change than in B1 and A2 families. In the Upper Cau river basin, there are available CC data for three meteorology stations: Bac Kan, Dinh Hoa and Thai Nguyen. All these figures were collected from MONRE.

3.2.1 Rainfall

3.2.1.1 Annual rainfall

The annual average rainfall at the stations has the increasing tendency under scenario B2. The average rainfall tendency by periods under Scenario B2 is shown in Table 3.9.

Table 3.9 The average rainfall by periods under scenario B2 (mm)

Period	1	2	3	4	5	6	7	8	9	10	11	12	Total	Flood Season	Dry Season
1980-1999	25	34	71	108	204	279	356	286	168	97	51	17	1692	1386	306
2020-2039	22	36	72	107	214	295	397	293	184	106	54	20	1800	1488	312
2040-2059	20	37	71	105	215	300	413	299	187	103	56	22	1826	1516	310
2060-2079	18	38	69	103	216	304	428	304	189	102	57	23	1851	1542	309
2080-2100	17	39	69	101	217	308	441	309	192	100	57	24	1872	1565	307

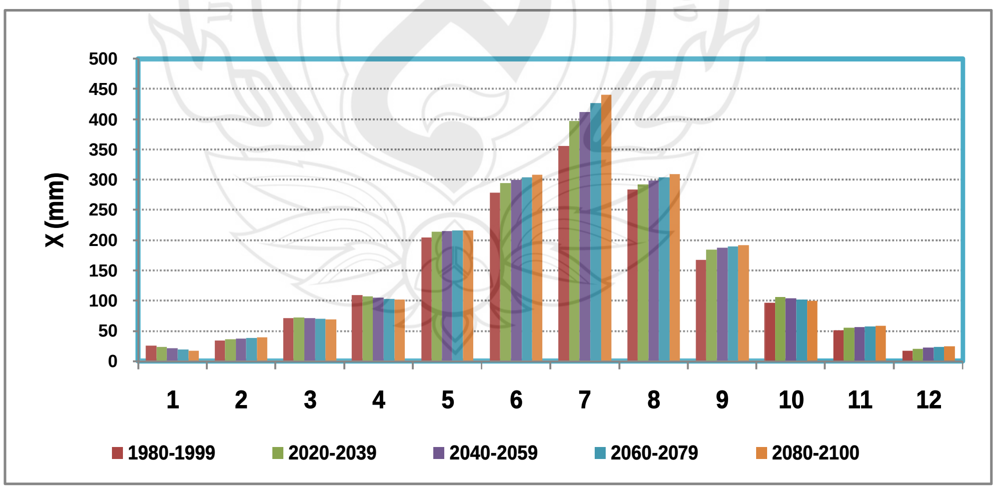
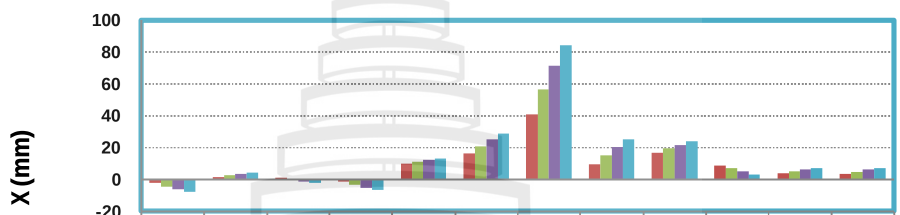


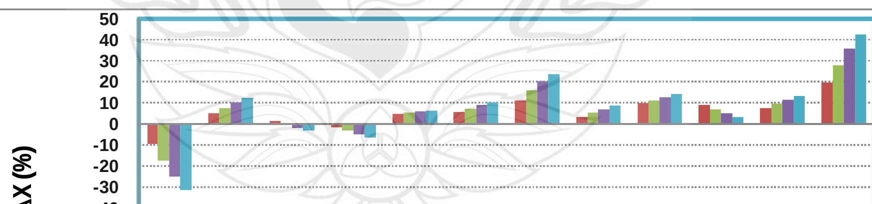
Figure 3.7 Monthly average rainfall by periods on Upper Cau river basin under scenario B2

Compared to the base period, the annual average rainfall in each period has remarkably increasing trend, the later periods increase faster than the previous ones. In the period of 2020-2039, in the scenario B2, the average annual rainfall increases compared to the base period with 6.4%, similarly, in the periods of 2040-2059, 2060-2079, 2080-2100 with the average rainfall change rate are 7.9%, 9.4%, 10.6%, respectively. The average rainfall change (mm) and the rate (%) by periods under scenario B2 compared to base period are shown in Table 3.7 and Table 3.8.



	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	-2.38	1.72	1.04	-1.62	10.02	16.21	40.93	9.41	16.63	8.85	3.94	3.34
2040-2059	-4.34	2.66	-0.15	-3.51	11.06	20.75	56.60	15.10	19.21	6.82	4.95	4.77
2060-2079	-6.24	3.57	-1.28	-5.38	12.02	25.20	71.72	20.55	21.70	4.87	5.96	6.11
2080-2100	-7.80	4.32	-2.22	-6.94	12.87	28.78	84.44	25.12	23.80	3.21	6.80	7.23

Figure 3.8 The average rainfall change by periods under scenario B2 compared to base period (mm)



	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	-9.5	5.0	1.5	-1.5	4.9	5.8	11.5	3.3	9.9	9.2	7.8	19.7
2040-2059	-17.4	7.8	-0.2	-3.2	5.4	7.4	15.9	5.3	11.5	7.1	9.8	28.0
2060-2079	-25.0	10.4	-1.8	-5.0	5.9	9.0	20.1	7.3	12.9	5.0	11.8	35.9
2080-2100	-31.2	12.6	-3.1	-6.4	6.3	10.3	23.7	8.9	14.2	3.3	13.5	42.5

Figure 3.9 The average rainfall change rate by periods under scenario B2 compared to base period (%)

For each station, the annual average rainfall by periods on Upper Cau river basin under CC scenario B2 is shown in Figure 3.10.

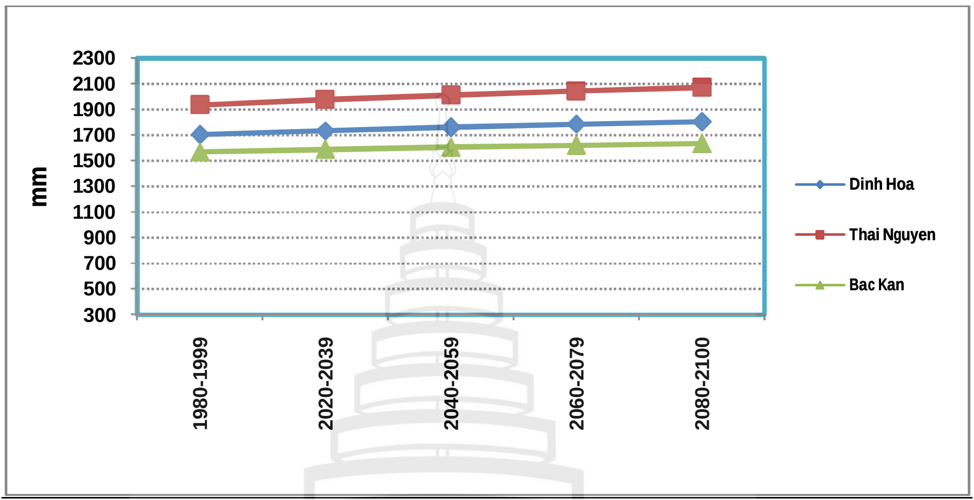
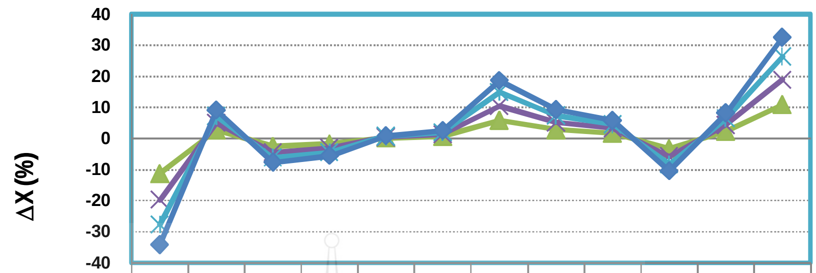


Figure 3.10 Annual average rainfall at stations by periods on Upper Cau river basin under scenario B2

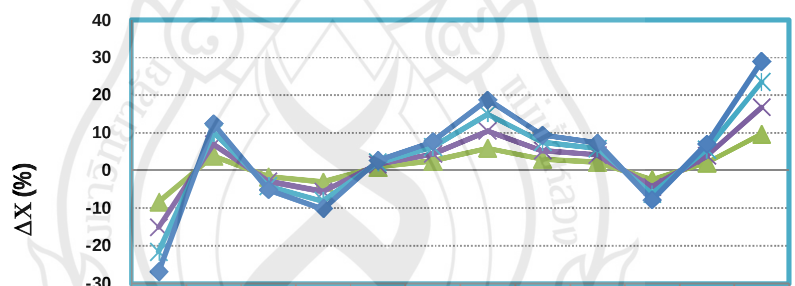
Compared with base period, the annual rainfall at Dinh Hoa station increases 31.49 mm/year (1.85%) in the period of 2020-2039 and upto 101 mm/year (5.93%) in 2080-2100. Similarly, at Thai Nguyen station, the figure is 43.13 mm/year (2.23%) in 2020-2039 and 135.34 mm/year (6.99%) in 2080-2100. With Bac Kan station, in 2020-2039 and 2080-2100, the annual rainfall increases 18.06 mm/year (1.15%) and 61.41mm/year (3.91%), respectively. It can be clearly seen that the increasing rate of rainfall in Thai Nguyen station is the largest in terms of amount as well as percentage rate, the least is at Bac Kan station.

Apparently, CC has changed the annual average rainfall considerably. The annual average rainfall has an increasing trend under scenario B2 at the three stations but the changes levels are different. The tendency is appropriate with the medium scenario of greenhouse gas emissions; the later periods it increases faster than the previous ones, especially in the period of 2060 – 2100.



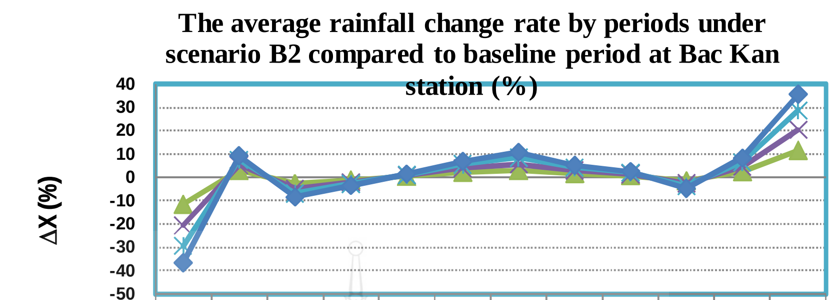
	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	-11.2	2.77	-2.53	-1.72	0.28	0.80	5.88	2.89	1.76	-3.22	2.40	10.91
2040-2059	-19.6	5.05	-4.40	-3.08	0.50	1.43	10.50	5.17	3.20	-5.81	4.46	18.89
2060-2079	-27.6	7.28	-6.18	-4.42	0.71	2.04	14.95	7.39	4.59	-8.31	6.50	26.36
2080-2100	-34.2	9.12	-7.64	-5.53	0.89	2.54	18.70	9.25	5.77	-10.4	8.22	32.57

Figure 3.11 The average rainfall change rate by periods under scenario B2 compared to base period at Dinh Hoa station (%)



	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	-8.36	3.85	-1.68	-3.11	0.85	2.46	5.93	3.04	2.26	-2.41	2.09	9.70
2040-2059	-15.0	6.96	-2.93	-5.60	1.52	4.36	10.56	5.35	4.09	-4.36	3.85	16.79
2060-2079	-21.5	9.98	-4.11	-8.07	2.14	6.21	15.02	7.55	5.85	-6.24	5.58	23.46
2080-2100	-26.9	12.47	-5.09	-10.1	2.68	7.71	18.75	9.38	7.34	-7.83	7.03	28.99

Figure 3.12 The average rainfall change rate by periods under scenario B2 compared to base period at Thai Nguyen station (%)



	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	-11.5	2.89	-2.78	-1.10	0.45	2.26	2.91	1.66	0.78	-1.44	2.42	11.54
2040-2059	-20.5	5.22	-4.86	-1.98	0.82	3.94	5.69	2.93	1.43	-2.62	4.49	20.30
2060-2079	-29.3	7.46	-6.84	-2.84	1.17	5.61	8.41	4.16	2.05	-3.78	6.57	28.66
2080-2100	-36.5	9.33	-8.46	-3.56	1.47	6.93	10.73	5.19	2.58	-4.75	8.31	35.61

Figure 3.13 The average rainfall change rate by periods under scenario B2 compared to base period at Bac Kan station (%)

3.2.1.2 Rainy season

Rainfall does not grow up in all months in year, it has the tendency of strong increase in rainy season and decrease in dry season. It is clear that in the future, the possibility of the flood appearance in rainy season and drought in the dry season is increasing on Upper Cau river basin.

From the three Figure 3.11, 3.12, 3.13 above, it can be seen that in rainy season, rainfall increases in most of months from May to October, especially the strongest is in July, but decreases at the end of the season (October). This situation is similar among three stations. However, in July, Bac Kan station has the least average rainfall change rate at the end of the century (10.73%) while the other 2 stations have those which are much higher (18.7% at Dinh Hoa and 18.75% at Thai Nguyen).

For the entire rainy season, changes rate of rainfall increases from 2.41% (2020-2039) upto 7.68% (2080-2099) at Dinh Hoa station. Likely, at Thai Nguyen the figures are 2.82% and 8.89% and at Bac Kan station they are 1.58% and 5.32%, respectively.

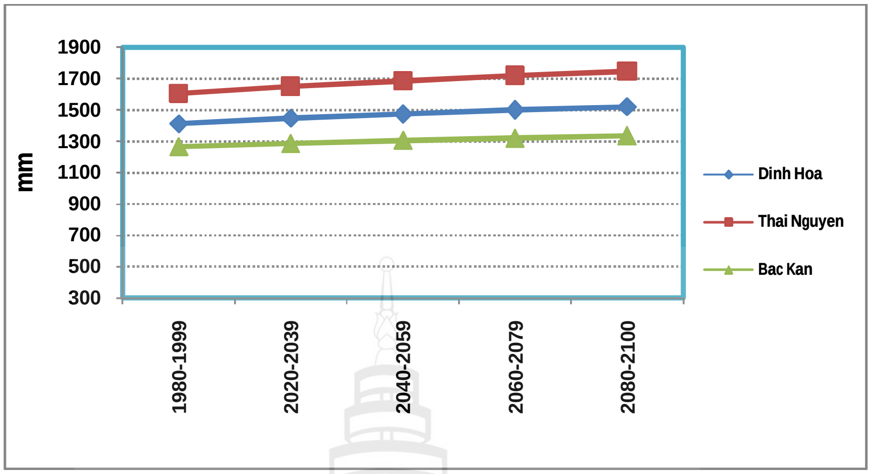


Figure 3.14 Increasing trend of average rainfall in rainy season on Upper Cau river basin under scenario B2

From the Figure 3.14 above, Dinh Hoa is still the station that has the biggest rainfall amount in rainy season and the least belong to Bac Kan station.

3.2.1.3 Dry season

In dry season, the tendency of average rainfall is downwards over the future periods of the 21st century. The strongestly decreasing rate of rainfall is in January at all three stations but the level is a little different with -34.25% rate for the whole month at Dinh Hoa, the least of -26.92% at Thai Nguyen and upto -36.6% at Bac Kan station.

At Dinh Hoa station, the rainfall change rate is biggest with -0.87% in the period of 2020-2039 and decreases to -2.56% at the end of the century. Meanwhile, Bac Kan and Thai Nguyen stations have the beginning rate at -0.66% and ends at -1.97% and -2.16%, respectively in the period of 2080-2100.

Decreasing trend of average rainfall in dry season on Upper Cau river basin is presented in Figure 3.15.

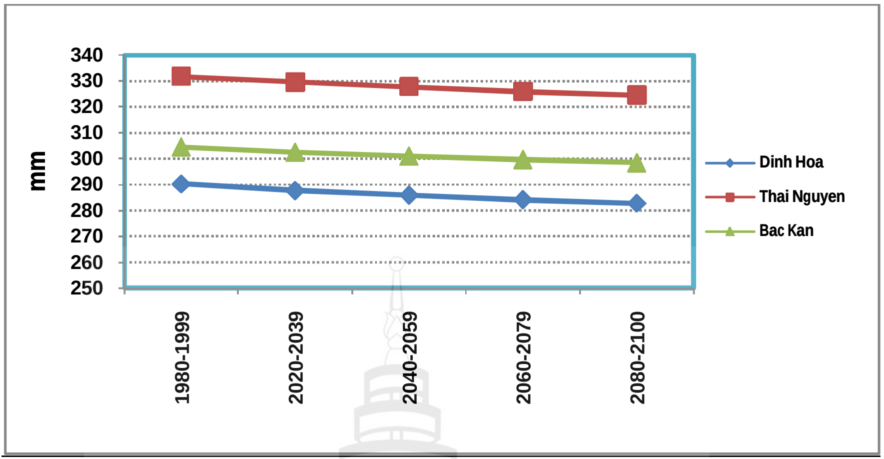


Figure 3.15 Decreasing trend of average rainfall in dry season on Upper Cau river basin under scenario B2

3.2.2. Temperature

In general, the annual average temperature on Upper Cau river basin has the increasing trend in the period of 2020 – 2100 under the impacts of CC.

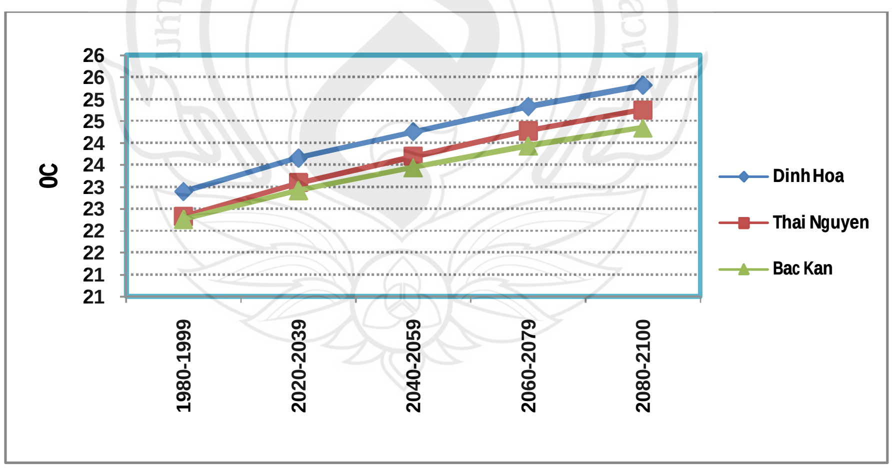
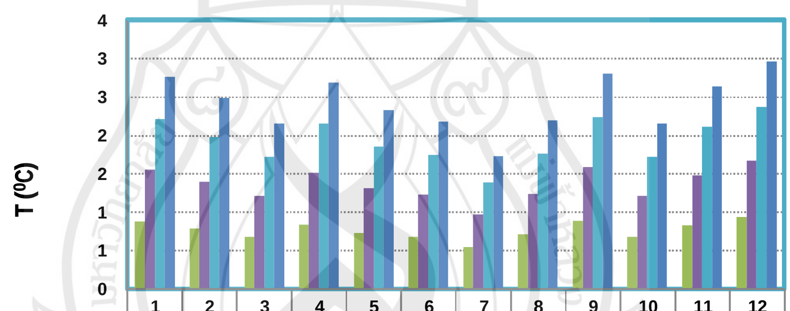


Figure 3.16 Annual average temperature at stations by periods on Upper Cau river basin under scenario B2

Figure 3.16 shows that the three stations have the temperature in the future increased steadily. Dinh Hoa has the highest annual average temperature with the temperature in the period of 2080-2100 of 25.31^{0}C, followed by Thai Nguyen with 24.76 ^{0}C and the least belongs to Bac Kan with 24.35^{0}C.

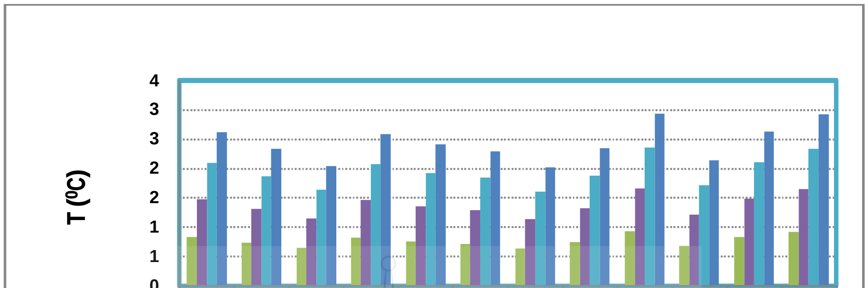
Changes of temperature (^{o}C) on Upper Cau river basin under B2 scenario compared to base period at the three stations are shown in Figure 3.17 to Figure 3.19. The results indicate that compared to base period 1980-1999, changes of temperature trend is quite similar at the three stations.

By the end of the twenty-first century, temperature rises highly at all three stations, the difference of nearly 3^{o}C compared to the base period 1980-1999 under scenario B2.



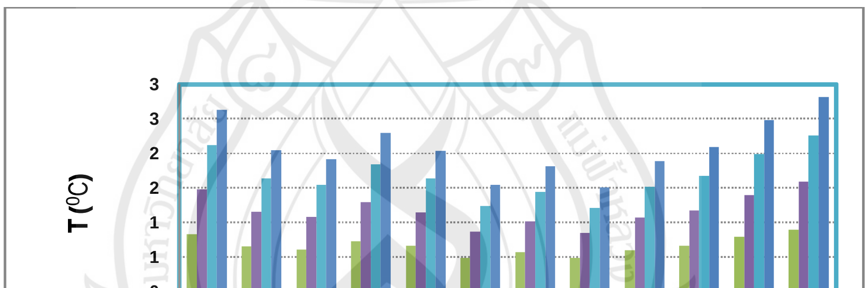
	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	0.88	0.78	0.68	0.84	0.73	0.68	0.55	0.71	0.89	0.68	0.83	0.94
2040-2059	1.55	1.40	1.21	1.51	1.31	1.23	0.97	1.24	1.58	1.21	1.48	1.67
2060-2079	2.21	1.98	1.73	2.15	1.85	1.75	1.38	1.76	2.23	1.72	2.11	2.37
2080-2100	2.75	2.48	2.15	2.68	2.33	2.18	1.73	2.19	2.81	2.16	2.64	2.96

Figure 3.17 Changes of temperature on Upper Cau river basin under B2 scenario compared to base period at Dinh Hoa station (^{0}C)



	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	0.83	0.73	0.64	0.82	0.76	0.71	0.63	0.75	0.93	0.68	0.83	0.92
2040-2059	1.48	1.31	1.15	1.46	1.35	1.29	1.13	1.32	1.66	1.21	1.48	1.64
2060-2079	2.10	1.86	1.63	2.08	1.92	1.84	1.61	1.87	2.35	1.71	2.11	2.34
2080-2100	2.62	2.33	2.04	2.59	2.40	2.29	2.01	2.34	2.94	2.14	2.63	2.91

Figure 3.18 Changes of temperature on Upper Cau river basin under B2 scenario compared to base period at Thai Nguyen station (^{0}C)



	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	0.84	0.64	0.61	0.72	0.65	0.48	0.57	0.48	0.60	0.66	0.78	0.89
2040-2059	1.48	1.15	1.08	1.29	1.15	0.87	1.02	0.85	1.07	1.17	1.39	1.59
2060-2079	2.11	1.64	1.54	1.84	1.63	1.24	1.45	1.21	1.52	1.67	1.99	2.26
2080-2100	2.64	2.05	1.92	2.30	2.04	1.54	1.81	1.51	1.89	2.09	2.48	2.82

Figure 3.19 Changes of temperature on Upper Cau river basin under B2 scenario compared to base period at Bac Kan station (^{0}C)

3.2.3 Evaporation

Evaporation is an important factor involved in the hydrological cycle, directly causes the change of flow and water balance in the basin. Consequences of CC are reflected in the marked change in air temperature that alters the amount of water evaporation in the basin. Due to the increase of temperature is quite strong, leading to potential evaporation on Upper Cau river basin tends to increase in the period of 2020 – 2100 under CC scenario B2 (Figure 3.20), however still increase much lower than that of rainfall. Table 3.10 shows the monthly and annual average evaporation in each period under Scenario B2.

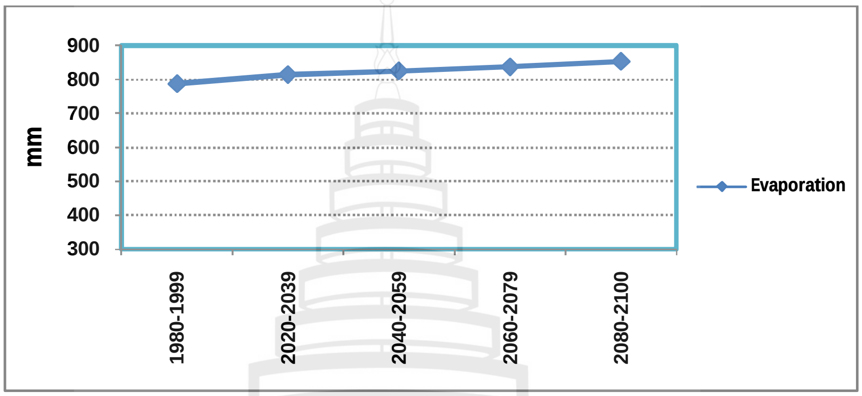
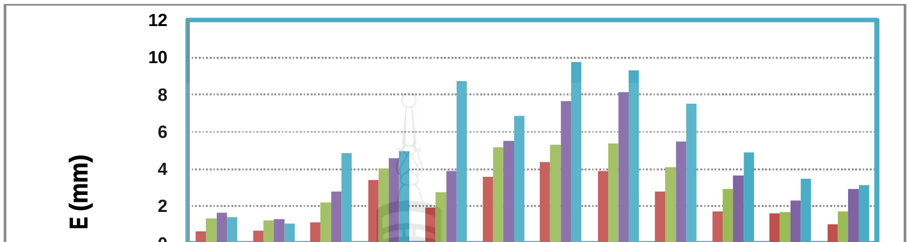


Figure 3.20 Annual average evaporation by periods on Upper Cau river basin under scenario B2

Table 3.10 The average evaporation by periods under Scenario B2 (mm)

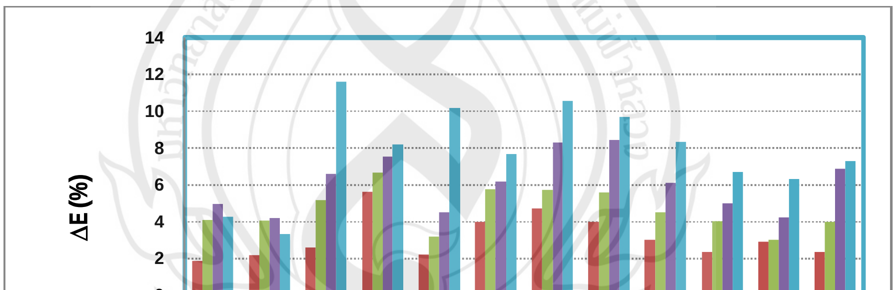
Period	1	2	3	4	5	6	7	8	9	10	11	12	Total
1980-1999	32.5	30.6	41.7	60.5	85.2	89.2	92.1	96	89.9	72.6	54.5	42.4	787.6
2020-2039	33.1	31.2	42.8	63.9	87.1	92.8	96.4	99.8	92.7	74.4	56.2	43.5	814.2
2040-2059	33.9	31.9	43.9	64.6	87.9	94.4	97.3	101.3	94.0	75.6	56.2	44.2	825.3
2060-2079	34.2	31.9	44.5	65.1	89.1	94.8	99.7	104.1	95.5	76.3	56.9	45.4	837.4
2080-2100	33.9	31.6	46.6	65.5	93.9	96.1	101.8	105.3	97.5	77.5	58.0	45.6	853.4

Changes of evaporation (mm, %) on Upper Cau river basin under B2 scenario compared to base period are shown in Figure 3.21 to Figure 3.22. The results indicate that compared to base period 1980-1999, the changes rate of evaporation goes upward quite steadily but strongest in the end of the century.



	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	0.62	0.67	1.09	3.40	1.90	3.56	4.36	3.86	2.74	1.72	1.60	1.00
2040-2059	1.34	1.25	2.16	4.02	2.72	5.15	5.29	5.36	4.07	2.93	1.66	1.69
2060-2079	1.62	1.29	2.75	4.57	3.85	5.52	7.62	8.10	5.49	3.63	2.32	2.93
2080-2100	1.39	1.02	4.83	4.95	8.68	6.86	9.75	9.30	7.48	4.88	3.46	3.11

Figure 3.21 Changes of evaporation on Upper Cau river basin under B2 scenario compared to base period (mm)



	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	1.90	2.19	2.60	5.61	2.23	3.99	4.73	4.02	3.05	2.37	2.93	2.35
2040-2059	4.10	4.07	5.17	6.65	3.20	5.77	5.74	5.58	4.53	4.03	3.04	3.97
2060-2079	4.97	4.20	6.58	7.55	4.51	6.19	8.28	8.44	6.10	4.99	4.25	6.89
2080-2100	4.26	3.34	11.57	8.18	10.19	7.68	10.59	9.69	8.31	6.71	6.34	7.31

Figure 3.22 Changes of evaporation on Upper Cau river basin under B2 scenario compared to base period (%)

3.3 Methodology

3.3.1 Data collection and synthesizing

This method is based on inheritance, analyzing and synthesizing relevant data sources, materials, information in a selective manner, thereby, to evaluate them according to the requirements and purposes of the research.

3.3.2 Statistics

This is a method of data processing in a quantitative manner and collection of measurement data, researched results of relevant programs, projects that have been implemented already.

3.3.3 SWAT model and GIS application

Overview of SWAT model is presented in Appendix A. Figure 3.23 shows the process of SWAT application.

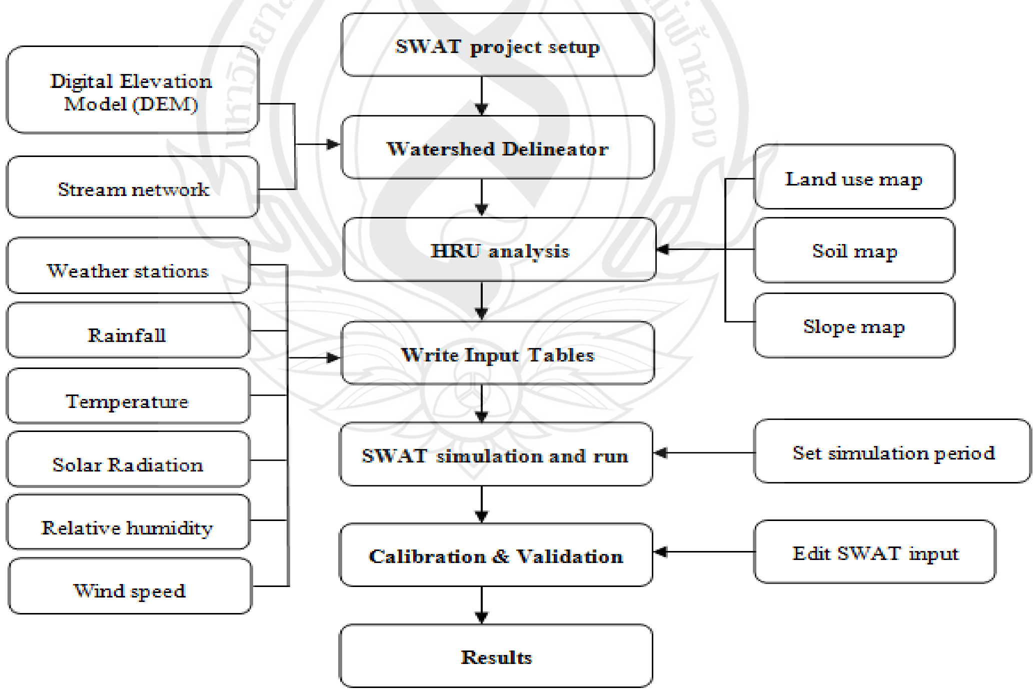


Figure 3.23 Process of SWAT application

The datasets which must be collected on Upper Cau River basin are all secondary data which are also the required data for SWAT model. To run the model, the input requirement data must be satisfied.

3.3.3.1 Spatial Datasets

Topographic map in the form of Digital Elevation Model (DEM) with 90-m resolution (Figure 3.24). DEM depends on the level of details of elevation of the terrain. Therefore, the accuracy of the model results depends very much on DEM terrain map.

Landuse (1993 data) and soil types, slope maps of Upper Cau River basin are put into the model in the form of grid or sharp. Table 3.10 below lists the soil types of the basin. Landuse map would be enhanced by applying RS in the next part.

3.3.3.2 Attribute Datasets (are put in the form of database)

Data for the present time: air temperature (maximum, minimum), average daily wind speed, radiation, relative humidity, precipitation, average monthly discharge and sediment discharge;

Data for the future: temperature and precipitation of CC scenario B2.

Data source: Vietnam Ministry of Natural Resources & Environment (MONRE)

3.3.4 Application of Remote Sensing (RS) in making Landuse map

Land use reflects human activities in using the land such as industrial areas, residential land and cultivated crops, etc. In order to make the map of land use in 1993 more precise, the study used RS for adjusting the Landuse map.

RS is a method that uses electromagnetic radiation as a mean to study, investigate, do survey of the basic properties of the research objects without direct exposure to the object. In the 1960s, the term "remote sensing" was first mentioned in the U.S., however the era of using RS to observe and study really began in 1972 with the successful launch of Landsat 1. So far, with more than 40 years of existence and development, RS has become a modern tool that is assistant and competitive in earth observation technology.

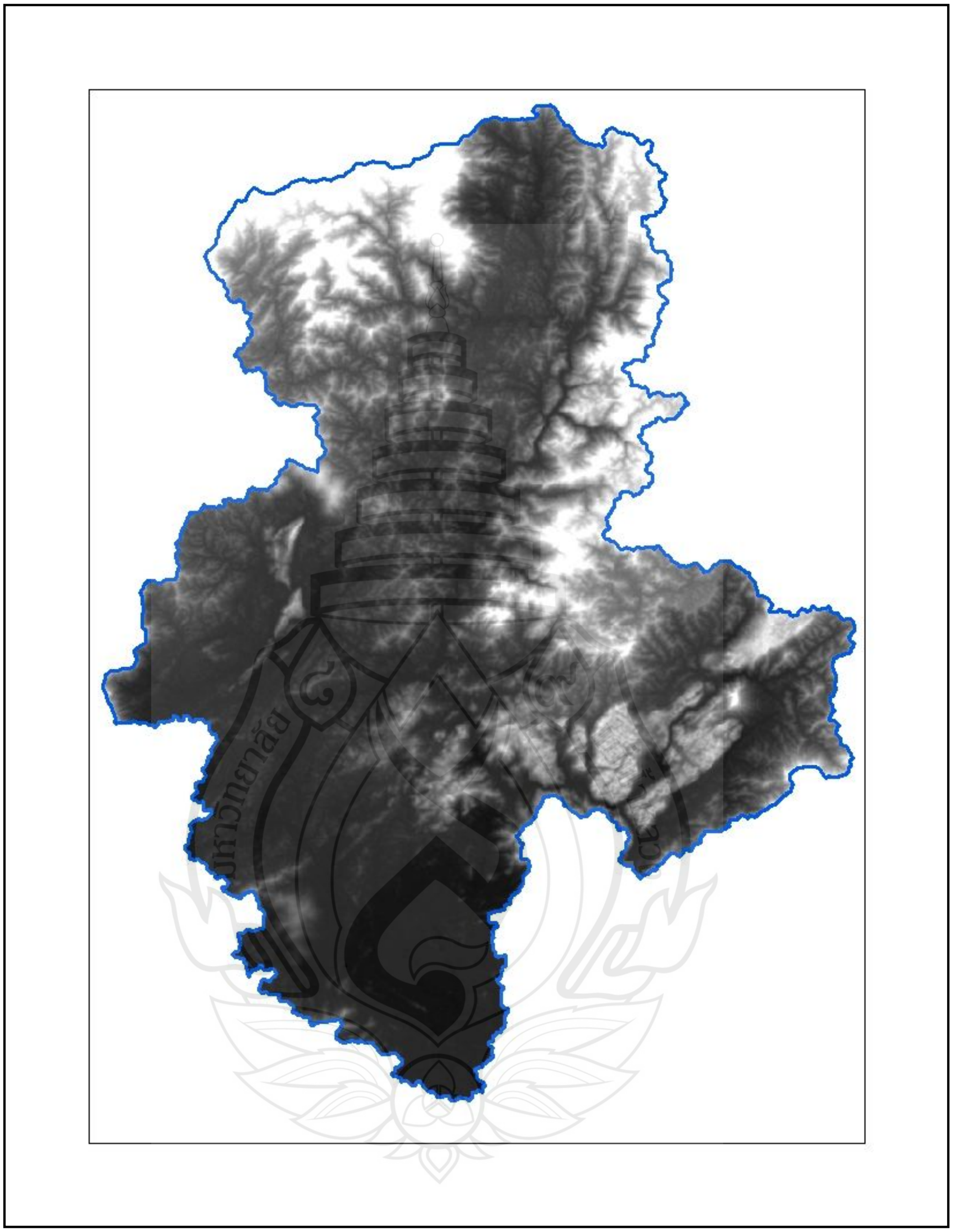


Figure 3.24 DEM of Upper Cau river basin

Accordingly, the applicability of RS imagery in the establishment of vegetation maps is increasingly improved and more widely used. Some of the advantages of RS are (1) provide objective, homogeneous, immediate, wide coverage information; (2) without Borders; (3) has repeated cycle that provides information; (4) capable of applying with GIS.

3.3.4.1 Applying RS

Firstly, the study downloaded Landsat image (resolution 30m x 30m) of the area of Upper Cau river basin from NASA website. Landsat image is Earth observation data obtained from high-resolution sensors on one of NASA's Landsat satellites.

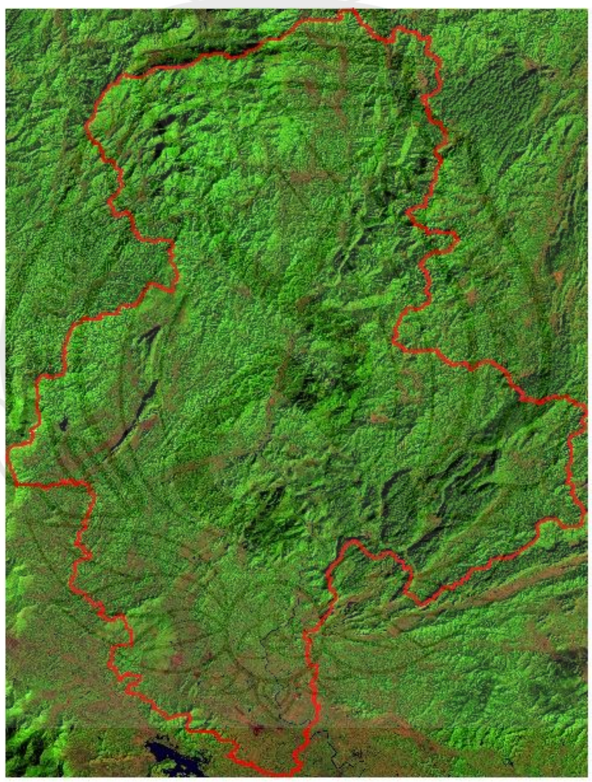


Figure 3.25 Raw Landsat image of Upper Cau river basin

Secondly, ENVI 4.5 (Environment for Visualizing Images – 1 software that processes well RS images) was used to process raw Landsat image. The enhancement process of sharpening (number) of the image to aid interpretation and transformation process of changing image including multi-channel data combination to create a new image were considered.

Then, image classification and analysis techniques were conducted. Image classification was classifying and arranging pixels in the image into different groups based on some common characteristics of the gray value, uniformity, density, image tone, etc. There were two main types of classification: Supervised and Unsupervised classification. In this part, the study used the Supervised classification. It was based on the sample pixels which were chosen by the analyst. By selecting the samples, the analyst helped the computer identify those pixels having the same characteristics of reflectance spectra.

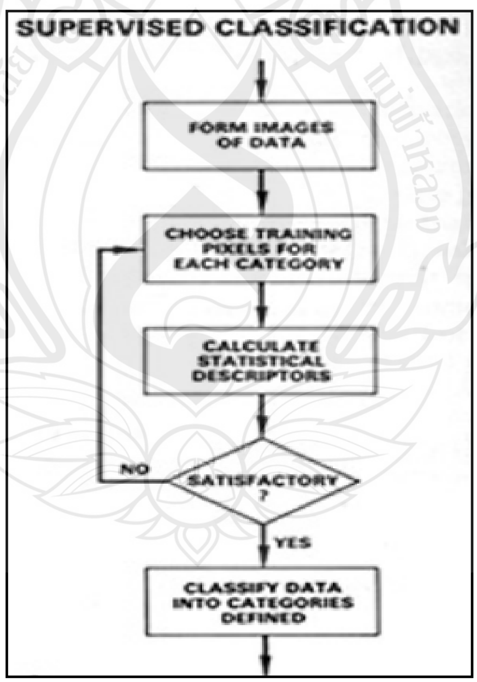


Figure 3.26 Steps of supervised classification

The the study identified the information about the object needed to be classified, groups of spectral values representing for that object (the objects was labeled prior to classifying). Classification samples were selected based on observed values in Landuse map. Then, the classification of maximum probability function - Maximum Likelihood was chosen. This method assumed that the spectral bands had the normal distribution and the pixels would be classified into class that they had the highest probability. The calculation was based not only on distance but also the trend of variation of gray value in each class. This was a accurate classification method but much time-consumed calculation and depended on the normal distribution of data. It had high precision and was widely used.

In postclassification process, to consolidate for the results, the study used Majority/Minority Analysis to gather the pixels which were sporadic or classified in the class into the class containing it. Then, classification to Vector Layer was conducted transforming classification results file into a vector file in order to make Landuse map in Mapinfo and ArcGIS.

3.3.4.2 Results

The study exported the residents area on Upper Cau river basin from Landsat image to combine with the surveyed Landuse map in 1993 to enhance the preciseness of data. The final result for the map of land use is presented on Figure 3.28 and land use types are shown at Table 3.11.

Table 3.11 List of land use types

No.	Name	SWAT Code
1	Forest-evergreen	FRSE
2	Forest-decicuous	FRSD
3	Hay	HAY
4	Rock	ROCK
5	Forest-mixed	FRST
6	Agricultural Land-generic	AGRL
7	Agricultural Land-close-grown	AGRC
8	Agricultural Land-Row Crops	AGRR
9	Residential-medium density	URMD

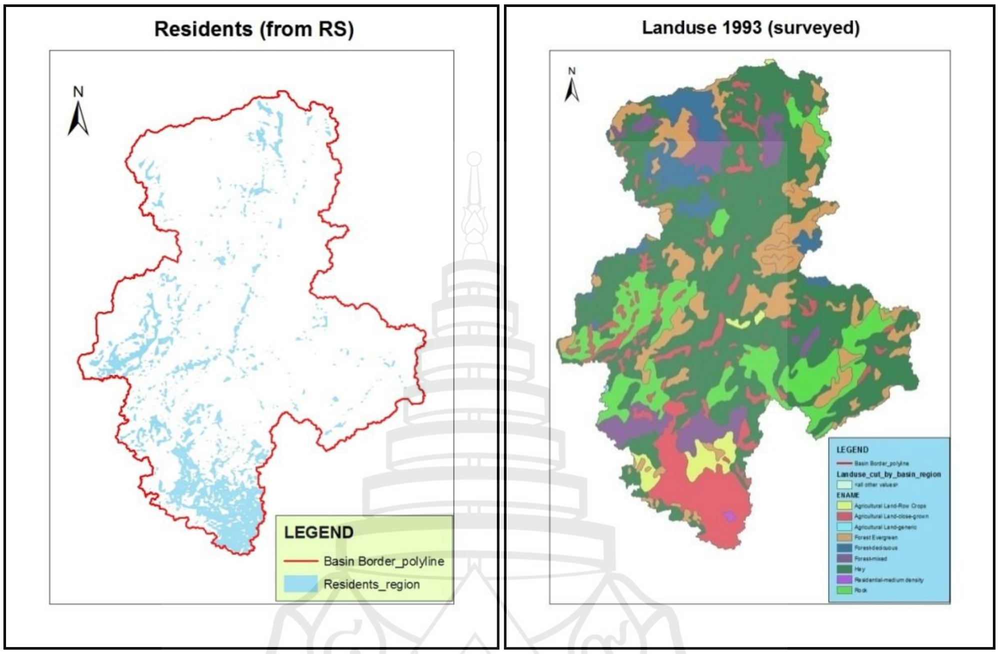


Figure 3.27 Maps of residents from RS and surveyed land use in 1993

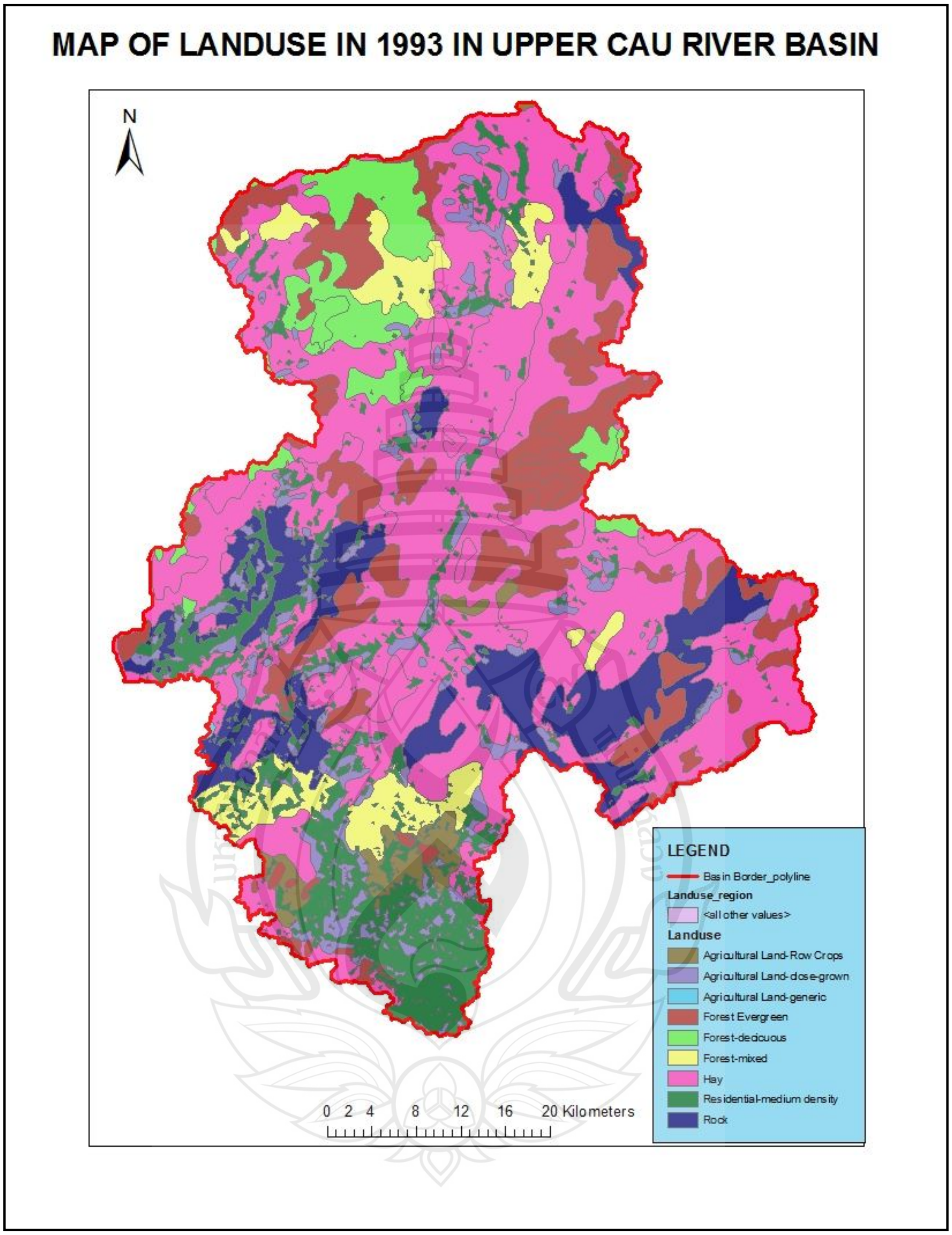


Figure 3.28 Map of land use in 1993 on Upper Cau river basin

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Basin Division

In SWAT, a watershed is divided into multiple subwatersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, topographical and soil characteristics. The HRUs are represented as a percentage of the subwatershed area and may not be contiguous or spatially identified within a SWAT simulation. The method of using sub-basins in the model in simulating the flow and sediment is very convenient when those sub-basins have enough datas on land use and soil characteristics.

Based on DEM, soil types, land use types, slope and rivers system, Upper Cau river basin restricted at Gia Bay station was divided into 35 subbasins and 355 HRUs. Each HRU in the basin has the area of approximately 8 km^2. Figure 4.1 shows the map of Upper Cau river basin division. The characteristics of the entire Upper Cau river basin and each subbasin were presented apparently with stations, types of soil, land use, slope, elevation and areas which were calculated through GIS software. Results were statistically calculated in Figure 4.2, 4.3 and Table 4.1. Thereby, the effects of the above factors on soil erosion of each subbasin would be stated.

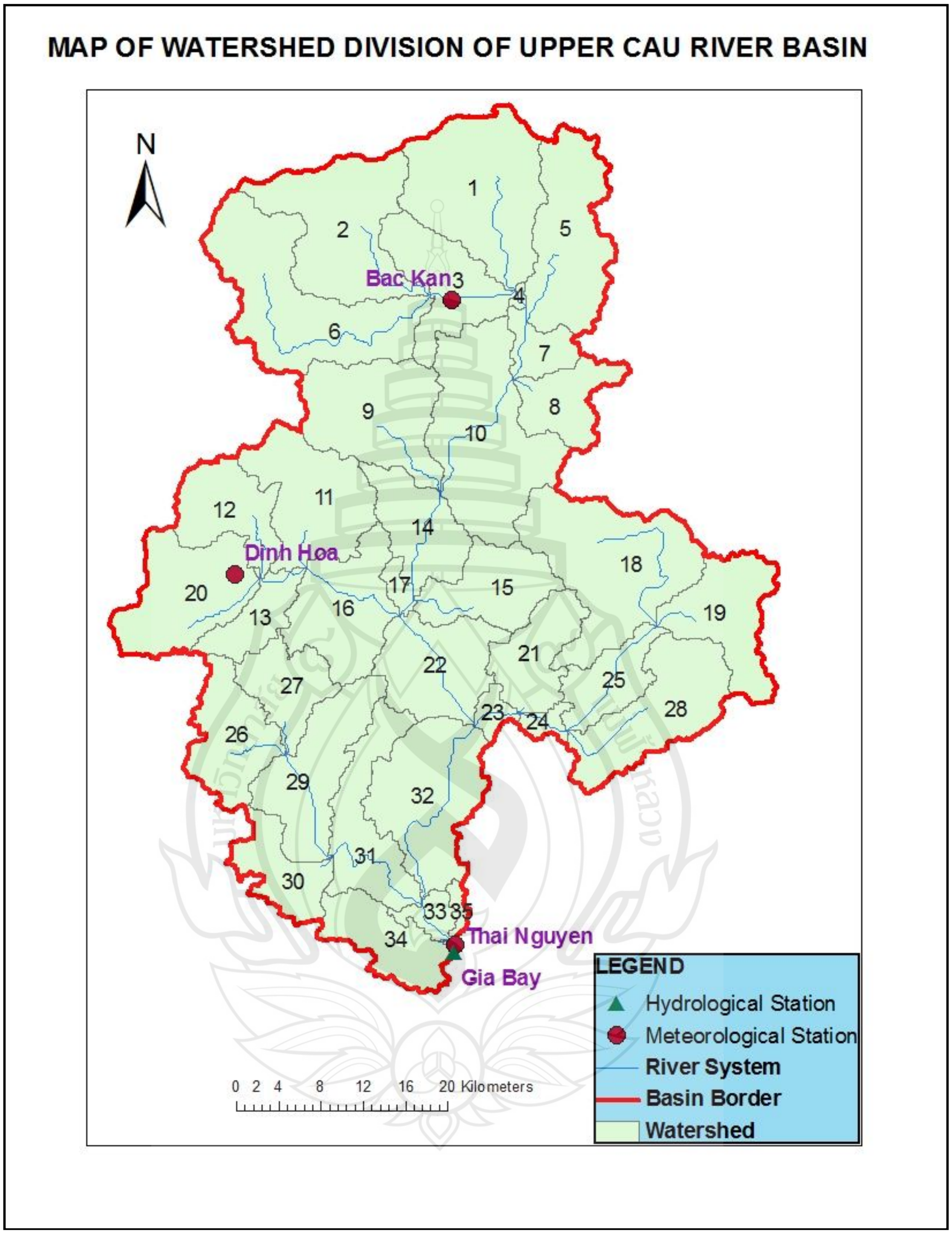
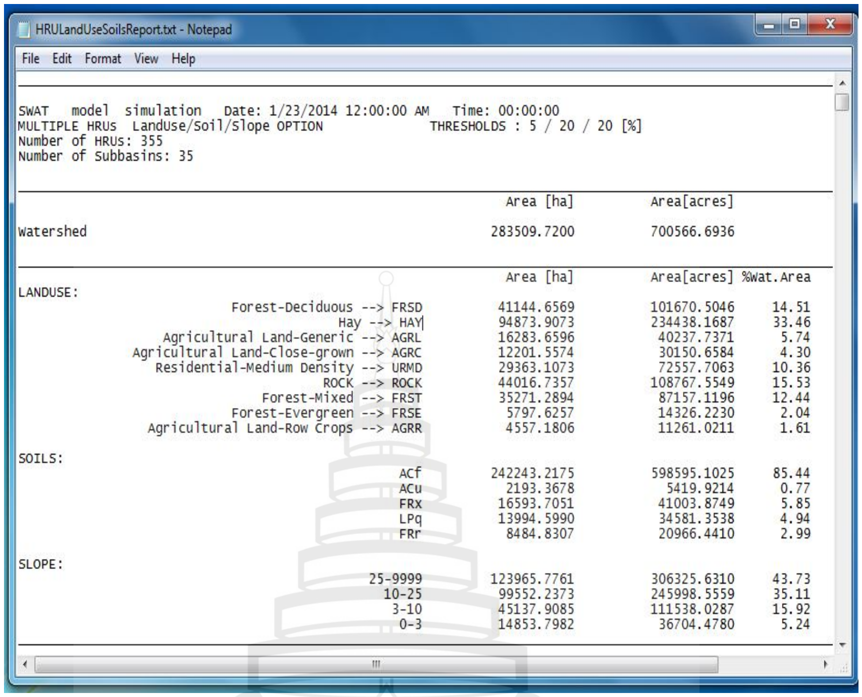


Figure 4.1 Map of Upper Cau river basin division

Table 4.1 List of hydrological characterisics of subbasins on Upper Cau river basin

Subbasin	Station	Area(km^2)	Slope	Elev (m)	ElevMin (m)	ElevMax (m)
1	Bac Can	158.58	23.04	213	111	1506
2	Bac Can	141.64	35.52	627	140	1511
3	Bac Can	82.36	21.55	204	88	1092
4	Bac Can	2.88	26.45	151	99	391
5	Bac Can	120.94	30.90	503	105	1075
6	Bac Can	172.30	29.17	364	138	1332
7	Bac Can	29.58	36.93	408	84	1021
8	Bac Can	54.40	34.68	640	110	972
9	Bac Can	119.28	22.80	287	76	708
10	Bac Can	173.03	28.31	261	60	961
11	Dinh Hoa	108.60	20.12	166	56	684
12	Dinh Hoa	70.37	20.48	226	74	666
13	Dinh Hoa	41.94	11.48	118	64	378
14	Dinh Hoa	70.65	25.86	187	31	891
15	Dinh Hoa	74.75	27.85	190	48	966
16	Dinh Hoa	99.87	16.97	93	44	531
17	Dinh Hoa	10.04	19.15	123	44	444
18	Bac Can	166.94	25.17	333	66	921
19	Bac Can	86.92	26.87	454	68	839
20	Dinh Hoa	108.77	14.08	143	75	702
21	Thai Nguyen	63.66	32.31	317	40	839
22	Dinh Hoa	93.21	29.61	50	25	699
23	Thai Nguyen	12.94	34.27	244	23	599
24	Thai Nguyen	11.38	42.61	79	35	689
25	Thai Nguyen	51.05	38.06	367	49	718
26	Dinh Hoa	79.10	10.22	122	45	452
27	Dinh Hoa	57.17	10.11	86	47	337
28	Thai Nguyen	111.55	26.21	129	41	840
29	Dinh Hoa	101.73	12.44	58	28	415
30	Thai Nguyen	54.07	12.17	69	-21	445
31	Thai Nguyen	86.61	8.51	34	17	612
32	Thai Nguyen	128.94	13.00	50	15	658
33	Thai Nguyen	16.69	4.34	27	13	175
34	Thai Nguyen	65.04	8.08	44	4	427
35	Thai Nguyen	8.15	5.11	33	9	139



```
HRULandUseSoilsReport.txt - Notepad
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SWAT  model  simulation   Date: 1/23/2014 12:00:00 AM   Time: 00:00:00
MULTIPLE HRUs  LandUse/Soil/Slope OPTION             THRESHOLDS : 5 / 20 / 20 [%]
Number of HRUs: 355
Number of Subbasins: 35

                                                          Area [ha]          Area[acres]

Watershed                                               283509.7200          700566.6936

                                                          Area [ha]          Area[acres] %Wat.Area
LANDUSE:
                            Forest-Deciduous --> FRSD    41144.6569          101670.5046     14.51
                                         Hay --> HAY     94873.9073          234438.1687     33.46
                  Agricultural Land-Generic --> AGRL     16283.6596           40237.7371      5.74
              Agricultural Land-Close-grown --> AGRC     12201.5574           30150.6584      4.30
                 Residential-Medium Density --> URMD     29363.1073           72557.7063     10.36
                                        ROCK --> ROCK    44016.7357          108767.5549     15.53
                                Forest-Mixed --> FRST    35271.2894           87157.1196     12.44
                            Forest-Evergreen --> FRSE     5797.6257           14326.2230      2.04
                Agricultural Land-Row Crops --> AGRR      4557.1806           11261.0211      1.61

SOILS:
                                                 ACf    242243.2175          598595.1025     85.44
                                                 ACu      2193.3678            5419.9214      0.77
                                                 FRx     16593.7051           41003.8749      5.85
                                                 LPq     13994.5990           34581.3538      4.94
                                                 FRr      8484.8307           20966.4410      2.99

SLOPE:
                                             25-9999    123965.7761          306325.6310     43.73
                                               10-25     99552.2373          245998.5559     35.11
                                                3-10     45137.9085          111538.0287     15.92
                                                 0-3     14853.7982           36704.4780      5.24
```
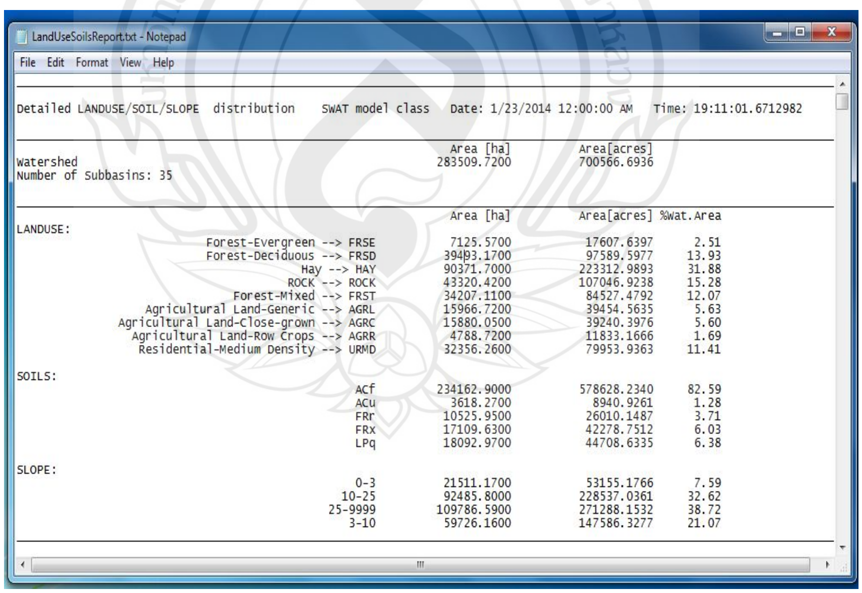

Figure 4.2 HRUs report



```
LandUseSoilsReport.txt - Notepad
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Detailed LANDUSE/SOIL/SLOPE  distribution    SWAT model class   Date: 1/23/2014 12:00:00 AM   Time: 19:11:01.6712982

                                                     Area [ha]          Area[acres]
Watershed                                          283509.7200          700566.6936
Number of Subbasins: 35

                                                     Area [ha]          Area[acres] %Wat.Area
LANDUSE:
                       Forest-Evergreen --> FRSE     7125.5700           17607.6397      2.51
                       Forest-Deciduous --> FRSD    39493.1700           97589.5977     13.93
                                    Hay --> HAY     90371.7000          223312.9893     31.88
                                   ROCK --> ROCK    43320.4200          107046.9238     15.28
                           Forest-Mixed --> FRST    34207.1100           84527.4792     12.07
              Agricultural Land-Generic --> AGRL    15966.7200           39454.5635      5.63
          Agricultural Land-Close-grown --> AGRC    15880.0500           39240.3976      5.60
            Agricultural Land-Row Crops --> AGRR     4788.7200           11833.1666      1.69
             Residential-Medium Density --> URMD    32356.2600           79953.9363     11.41

SOILS:
                                            ACf    234162.9000          578628.2340     82.59
                                            ACu      3618.2700            8940.9261      1.28
                                            FRr     10525.9500           26010.1487      3.71
                                            FRx     17109.6300           42278.7512      6.03
                                            LPq     18092.9700           44708.6335      6.38

SLOPE:
                                            0-3     21511.1700           53155.1766      7.59
                                          10-25     92485.8000          228537.0361     32.62
                                        25-9999    109786.5900          271288.1532     38.72
                                           3-10     59726.1600          147586.3277     21.07
```

Figure 4.3 Basin report

4.2 Model Calibration and Validation

Calibration is the process by which a model is adjusted to more closely match some observed data. Calibration greatly improves the accuracy of a model. The main purpose of the calibration process of model is to achieve a stable set of parameters of the model for the study area. Calibrating model parameters is to make the simulated process most suitable with the observed process. The calibration of model parameters is carried out by adjusting the model parameters using the trial and error method.

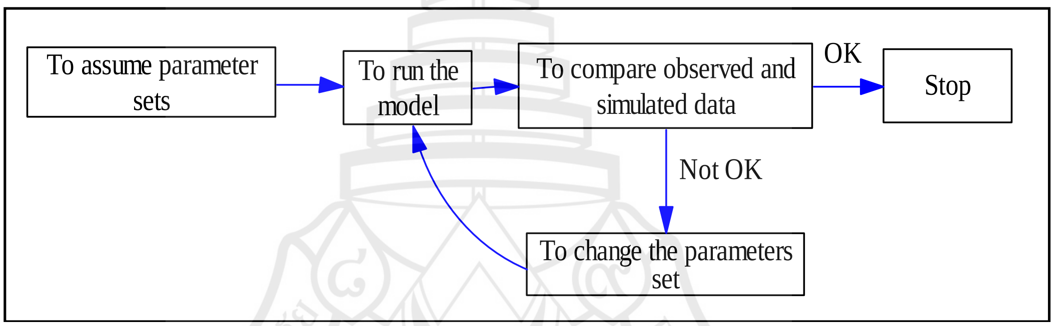


Figure 4.4 Diagram of the calibration process of the model parameters set

Calibration is summarized into several steps:

Step 1: Assume the parameters, initial conditions.

Step 2: Once the parameters have been assumed, the model runs.

Step 3: Compare the calculated results with measured data at the stations have measurements of flow and sediment.

This comparison can be carried out by visual (compare 2 lines: the calculated and measured ones on the chart), and integrating with Nash criteria for checking. SWAT model using criteria of Nash - Sutcliffe (1970) to evaluate the model. It is written as follows:

$$R^2 = \frac{\sum_{i-1}^{n}(x_i - \bar{x})^2 - \sum_{i-1}^{n}(x_i^{'} - x_i)^2}{\sum_{i-1}^{n}(x_i - \bar{x})^2}$$

In which:

R^2 : Effective coefficient of the model

i : Index

x_i : Observed value

x'_i : Simulated value according to the model

$\bar{x}$: Average observed value

The effective coefficient is usually less than 1 and greater than 0.

Table 4.2 The level of model simulations corresponding to Nash index

R^2	0.9-1	0.7 - 0.9	0.5 – 0.7	0.3 - 0.5
Simulation level	Very good	Good	medium	Poor

Step 4: If the results compared well, stop and save the calibration parameters. If the results are not achieved, analyze and assess the difference, then continue to calibrate the parameters.

Moreover, according to Moriasi et al. (2007), the study also used the other recommended model evaluation method - Percent bias (PBIAS). For PBIAS, constituent-specific performance ratings were determined based on uncertainty of measured data. PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. PBIAS is calculated with equation:

$$PBIAS = \left[\frac{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim}) * (100)}{\sum_{i=1}^{n} (Y_i^{obs})} \right]$$

Where PBIAS is the deviation of data being evaluated, expressed as a percentage.

Table 4.3 The level of model simulations corresponding to PBIAS index

No.	Simulation level	Value
1	Very good	< ±15%
2	Good	±15% ≤PBIAS < ±30%
3	Satisfactory	±30% ≤ PBIAS < ±55%
4	Unsatisfactory	PBIAS ≥±55%

In general, model simulation can be judged as satisfactory if NSE > 0.50 and if PBIAS ± 25% for streamflow, PBIAS ± 55% for sediment.

Model validation is the process of re-running the simulation, using a different time-series for input data, without changing any parameter values which may have been adjusting during calibration. Validation can also occur during the same time-period as calibration, but at a different spatial location.

In this study, SWAT model was first calibrated and then validated by using monthly observed stream flow and sediment discharge at Gia Bay station. The data of monthly discharge of the period 1980 -1999 (base period) was divided into 2 periods: 1991 – 1999 and 1980 – 1990 for calibration and validation, respectively. Similarly, for monthly sediment data, calibration and validation processes periods were 1981 – 1990 and 1991 – 1996.

SWAT is a comprehensive, semi-distributed river basin model that requires a large number of input parameters, which complicates model parameterization and calibration. The study focused on calibrating parameters influencing on the base flow and underground flow. They include parameters of surface runoff formation calculation, parameters of ground water calculation and parameters of erosion and nutrients transfer calculation.

In the parameters of surface runoff formation calculation, the CN2 (Initial SCS runoff curve number for moisture condition II) were adjusted within 10 percent from the tabulated curve numbers to reflect conservation tillage practices and soil residue cover conditions of the watershed. When CN2 was increased, the flood peak increased, process of upgoing flood dis not increase, while the process of reducing flood decreased. This demonstrated that surface runoff layer depends on the conditions of land use and land cover as well as soil moisture in the basin. If the

SOL_AWC (available water capacity of the soil layer) or SOL_K (saturated hydraulic conductivity) were increased or decreased, the flood peak also changed. Thereby, it was found that flood peak on the basin depends clearly on forest cover and soil moisture conditions. Moreover, some other parameters such as ESCO (Soil evaporation compensation factor) and EPCO (Plant uptake compensation factor) were adjusted as well.

Parameters influencing on the underground flow were also adjusted including GW_DELAY (Ground water delay), ALPHA_BF (Baseflow alpha factor), GW_QMN (Threshold depth of water in the shallow aquifer required for return flow to occur), REVAPMN (Threshold depth of water in the shallow aquifer for revap to occur), GW_REVAP (Groundwater revap coefficient).

Finally, parameters of erosion transfer calculation were increased and decreased for calibration. They are USLE_K1 (USLE equation soil erodibility (K) factor), USLE_C (Cover or management factor), USLE_P (USLE equation support practice factor), BIOMIX (Biological mixing efficiency), CH_COV (Channel cover factor), CH_EROD (Channel erodibility factor), SLSUBBSN (Average slope length), linear factor (SPCON) and exponential factor (SPEXP) which controls the balance between deposition and degradation in the channel for channel sediment routing, and Residue decomposition coefficient (RSDCO).

An optimal parameter set is shown as follows in Table 4.4.

Table 4.4 List of the most sensitive calibrated parameters

No.	Parameters	Discription	Value
I. The parameters of surface runoff formation calculation			
1	CN2	Initial SCS runoff curve number for moisture condition II	35-98
2	SOL_AWC	Available water capacity of the soil layer (mm/mm)	0-1
3	EPCO	Plant uptake compensation factor	0
4	ESCO	Soil evaporation compensation factor	0.002
II.The parameters of ground water calculation			
5	GW_DELAY	Ground water delay (days)	150

Table 4.4 (continued)

No.	Parameters	Discription	Value
6	ALPHA_BF	Baseflow alpha factor (days)	0.048
7	GW_QMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	100
8	REVAPMN	Threshold depth of water in the shallow aquifer for revap to occur (mm)	0
9	GW_REVAP	Groundwater revap coefficient	0.2
IV. The parameters of erosion calculation			
10	USLE_K1	USLE equation soil erodibility (K) factor	0-0.65
11	USLE_C	Cover or management factor	0.001–0.2
12	USLE_P	USLE equation support practice factor	0.4
13	BIOMIX	Biological mixing efficiency	0.2
14	CH_COV	Channel cover factor	0.02
15	CH_EROD	Channel erodibility factor	0.02
16	SLSUBBSN	Average slope length (m)	10-150
17	SPEXP	exponential factor	1
18	SPCON	linear factor	0.0001
19	RSDCO	Residue decomposition coefficient	0.05

4.2.1 Flow

The period which was selected for calibration process for flow is 1991 – 1999 with data of monthly discharge. The lines of observation and simulation processes show that the flow is relatively consistent. Results show the relevance between observed and simulated discharge with the correlation coefficient Nash is R^2 = 0.85, achieved fair results and PBIAS = -3.68 achieved very good results. The difference between the simulated and observed results is evident in the flood season, the simulated values are smaller than the observed values. Except this, the model simulated the process with high accuracy.

From the results of calibrated parameters, the study conducted validation process. Time series for this process is the observed monthly discharge from 1980 –

1990 at Gia Bay station. Similarly, results of validation process is Nash = 0.81 and PBIAS = -2.54 achieved fair and very good results, respectively (Table 4.5).

Results of correlation curves and cumulative sum between observed and simulated discharge at Gia Bay station for calibration and validation processs is shown in Figure 4.5 and Figure 4.6. And Figure 4.7 shows the observed and simulated discharge values in two processes of calibration and validation in scatter format with their trendlines.

Table 4.5 Results of calibration and validation of model parameters for flow

No.	Process	Period	Index	
			NASH	PBIAS
1	Calibration	1991 - 1999	0.85	-3.68
	Validation	1980 - 1990	0.81	-2.54
2	Simulation level		Good	Very good

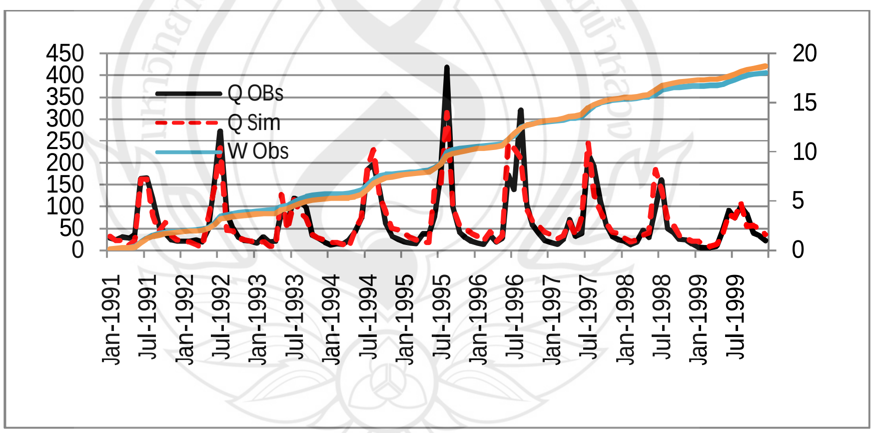


Figure 4.5 Observed and simulated discharge correlation curves and cumulative sum at Gia Bay station for calibration process

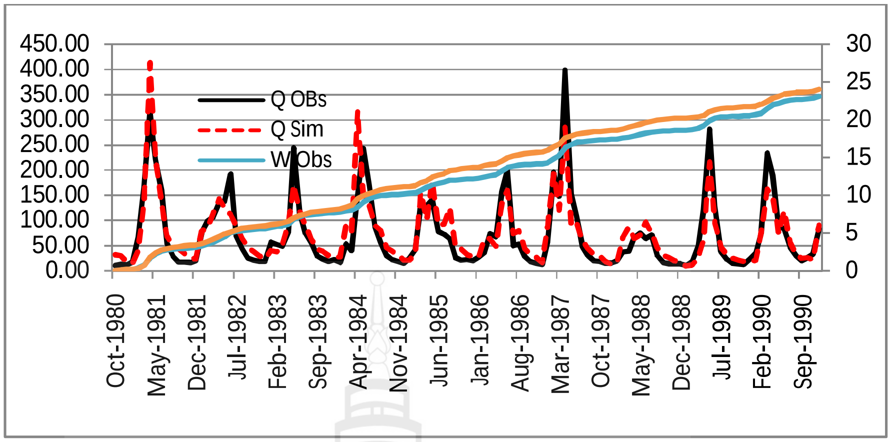


Figure 4.6 Observed and simulated Discharge correlation curves and cumulative sum at Gia Bay station for validation process

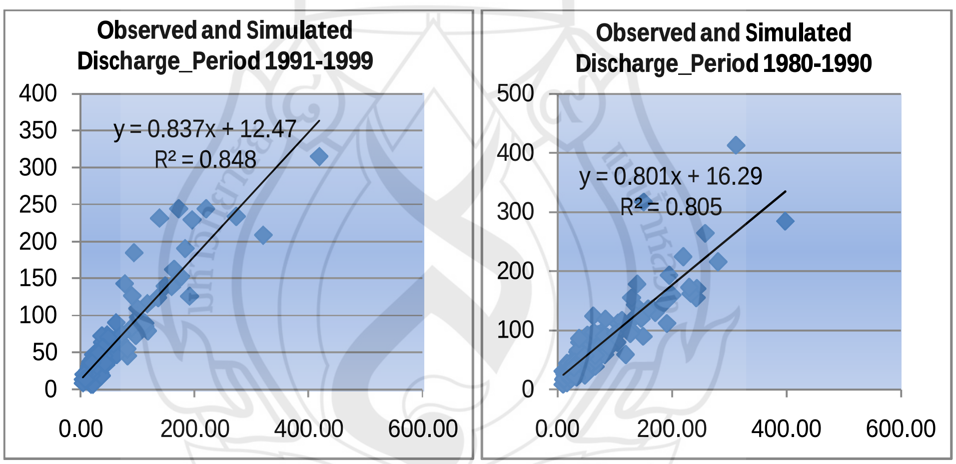


Figure 4.7 The observed and simulated discharge values in two processes of calibration and validation

4.2.2 Sediment discharge

Likely, for monthly sediment discharge data, calibration processes period is chosen with the period of 1980 – 1990 and 1991 – 1996 is for validation. Results of calibration process is Nash = 0.66 and PBIAS = -10.86 achieved medium and very good results, respectively. Meanwhile, the validation process has the correlation coefficient with Nash = 0.58 and PBIAS = 11.8 achieved the same simulation levels results (Table 4.6).

Figure 4.8 and Figure 4.9 indicate correlation curves and cumulative sum between observed and simulated sediment at Gia Bay station for calibration and validation processes. And Figure 4.10 shows the observed and simulated sediment values in two processes of calibration and validation in scatter format with their trendlines.

Table 4.6 Results of calibration and validation of model parameters for sediment discharge

No.	Process	Period	Index	
			NASH	PBIAS
1	Calibration	1980 - 1990	0.66	-10.86
	Validation	1991 - 1996	0.58	11.81
2	Simulation level		Medium	Very good

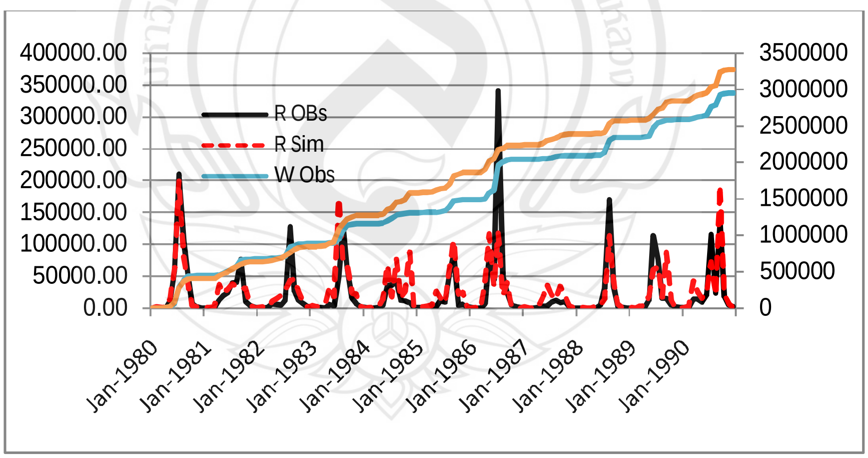


Figure 4.8 Observed and simulated sediment correlation curves and cumulative sum at Gia Bay station for calibration process

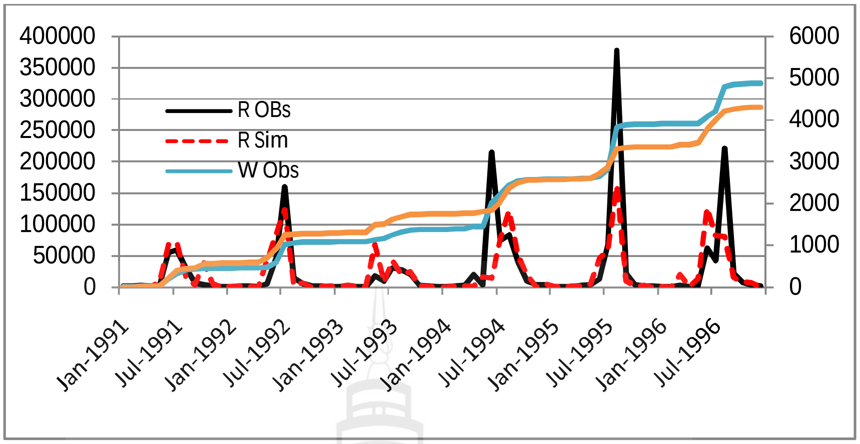
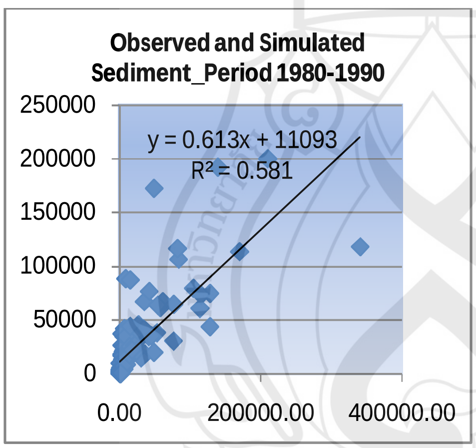


Figure 4.9 Observed and simulated sediment correlation curves and cumulative sum at Gia Bay station for validation process



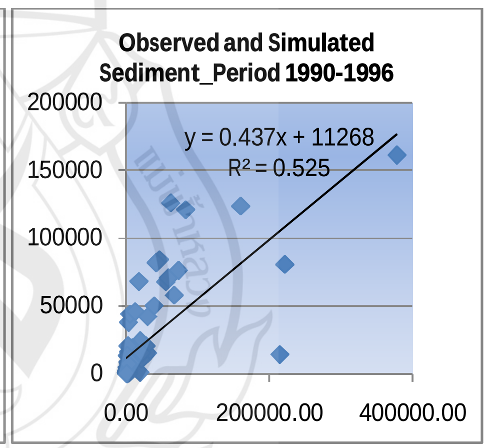


Figure 4.10 The observed and simulated sediment values in two processes of calibration and validation

Results of calibration and validation show that SWAT is capable of simulating the flow with the conditions of the study area with relatively high accuracy. On the other hand, for sediment discharge, one of the reasons causing discrepancy between simulated and observed sediment discharge may be attributed to channel erosion, especially during high flows and instability of sediment yields. Other factors include SWAT's inadequate description of channel scouring process and the presence of temporary channel embankment used by farmers to retard channel flow velocity. Moreover, the small number of meteorological stations in the basin is also one of the reasons for that. Nevertheless, these results ensure the calibrated parameters are suitable to be used to assess the flow and sediment changes under the context of CC. The overall adequacy of SWAT to simulate flow and sediment discharge in the watershed indicates its usefulness as a management tool to predict the effects of land use changes in midsize watersheds.

4.3 Impacts of Climate Change on Flow Regime and Erosion

The incoming flow and soil loss (or erosion) to Gia Bay hydrological station and subbasins of the Upper Cau river basin were calculated under the CC scenario B2 with the periods of 2020 - 2039, 2040 - 2059, 2060 - 2079, 2080 – 2099 compared to the base period of 1980 -1999. Results of discharge and sediment yield (soil loss) from SWAT model are presented in Appendix B.

4.3.1 Flow regime changes over time

4.3.1.1 Annual flow

The total annual runoff on Upper Cau river system tends to increase compared to the base under the CC scenario B2.

The changes of the annual flow in each period are different. In the three periods (2020-2039, 2040-2059 and 2060-2079) in the CC scenario B2 the flow increases steadily but in the period of 2080-2099, the flow has the little decreasing trend compared to the other previous periods. Compared to the base period, the flow increases by 0.15 m^3/s (0.22%) in period of 2020-2039 upto 0.96 m^3/s (1.37%) (2060-2079), then it increases only 0.73 m^3/s (1.03%) (2080-2099).

Regarding to the monthly average runoff on Upper Cau river basin, at Gia Bay station, some months like III, IV, V and X, XI, XII has the decreasing runoff tendency while the runoff in VII and VIII has the tendency of increase. Especially, VI and IX have the decreasing runoff trend in the early half of the century but steadily go up in the last half. With I and II, the runoff increases in the period of 2020-2039 but decreases in the remaining periods.

In summary, it can be seen clearly that the annual average runoff on Upper Cau river basin has the increasing trend compared to the base period 1980-1999 and the changes rate of the later periods is bigger than the previous ones, appropriate with the changing tendency of evaporation and rainfall of the scenario B2 (rainfall increases much but evaporation increases less leading to the annual runoff increases). Especially, the difference is shown apparently in the last half of the century.

The average flow in each period and its changes under the CC scenario B2 at Gia Bay station (m^3/s) are seen at Table 4.7 and 4.8.

Table 4.7 The average flow by periods under scenario B2 at Gia Bay station (m^3/s)

Period	1	2	3	4	5	6	7	8	9	10	11	12	Average	Flood Season	Dry Season
1980-1999	30	24	24	29	59.3	112	170	139	105	65	51	35	70.3	108.4	32.2
2020-2039	30	24	24	27	57.4	112	178	141	104	63	51	35	70.5	109.3	31.7
2040-2059	29	23	22	25	56.0	112	187	144	105	62	51	35	70.8	110.8	30.7
2060-2079	29	23	22	24	54.6	113	194	145	106	61	51	35	71.3	112.3	30.3
2080-2100	28	22	21	23	51.4	112	200	146	106	59	50	34	71.0	112.4	29.6

Table 4.8 The changes of average flow by periods compared to base period under scenario B2 at Gia Bay station (m^3/s)

Period	1	2	3	4	5	6	7	8	9	10	11	12	Average	Flood Season	Dry Season
2020-2039	0.4	0.3	-0.4	-2.3	-1.9	-0.4	8.6	1.6	-0.4	-2.3	-0.9	-0.5	0.15	0.88	-0.57
2040-2059	-1.1	-0.9	-1.7	-4.3	-3.3	-0.1	16.9	4.0	0.4	-3.3	-0.7	-0.5	0.45	2.45	-1.54
2060-2079	-1.5	-0.9	-2.2	-5.5	-4.7	1.0	24.5	5.8	0.8	-4.2	-0.8	-0.8	0.96	3.88	-1.95
2080-2100	-1.8	-1.1	-3.2	-6.8	-7.9	0.3	30	7.0	0.8	-5.8	-1.6	-1.2	0.73	4.07	-2.62

CC affects on the flow due to the changes of rainfall regime and evaporation. The results of calculating the annual average Rainfall - Evaporation - Runoff and the annual flow coefficient (α=Y/X) under the Scenario B2 on Upper Cau river basin restricted at Gia Bay staion are shown at Figure 4.11 and Table 4.9. The flow coefficient on the river system decreases a little in the scenario B2. In Table 4.9, the column of Runoff was the total of 12 months' runoff. In each month, the value was calculated on the basis of the following equation:

$$A_{xy} = (B_{xy} * 10^9 * 3600 * 24 * C_x)/(D*10^{12})$$

In which:

Axy: The monthly average runoff in each period (mm)

x: each month in a year → x = 1,2,3,4,5,6,7,8,9,10,11,12

y: each period → y = 1980-1999, 2020-2039, 2040-2059, 2060-2079, 2080-2099

Bxy: The monthly average discharge in each period (m^3/s)

Cx: the number of days in each month (days)

D: the area of the basin (km^2)

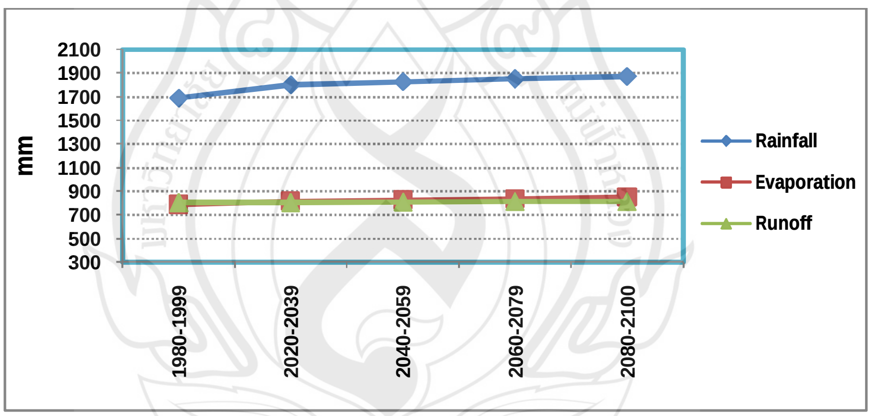


Figure 4.11 Annual average Rainfall - Evaporation - Runoff by periods on Upper Cau river basin under scenario B2

Table 4.9 Rainfall – Evaporation – Runoff calculated upto Gia Bay station under scenario B2 (mm)

Period	Rainfall	Evaporation	Runoff	Flow coefficient
1980-1999	1692.03	787.69	805.65	0.48
2020-2039	1800.12	814.20	807.37	0.45
2040-2059	1825.95	825.33	810.76	0.44
2060-2079	1850.84	837.37	816.58	0.44
2080-2100	1871.65	853.39	813.86	0.43

The simulated discharge continuity curve at Gia Bay station in the future periods and base period under Scenario B2 is shown in Figure 4.12. Changes of flow on Upper Cau river basin under B2 scenario compared to base period (m^3/s and %) are presented in Figure 4.13 and 4.14.

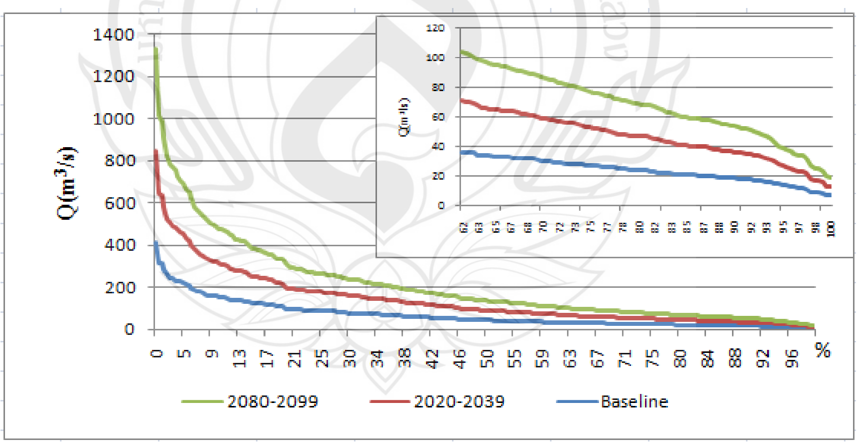
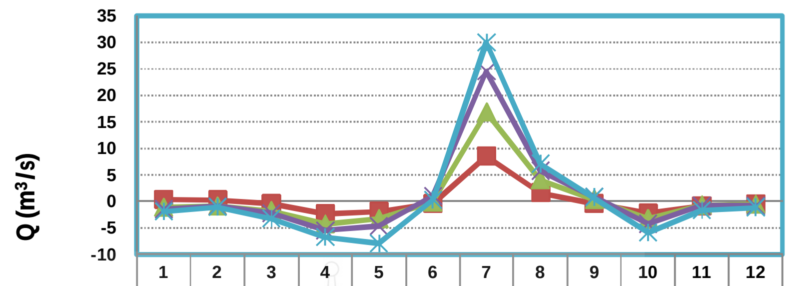
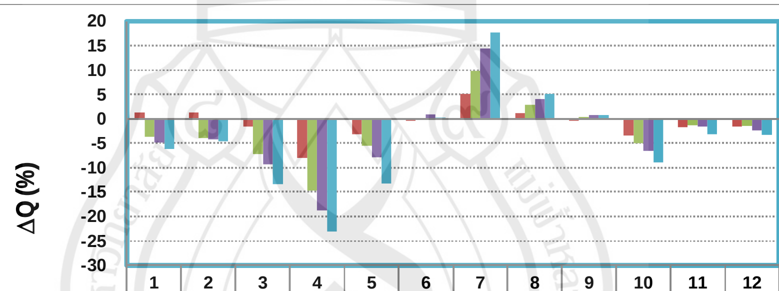


Figure 4.12 The simulated discharge continuity curve at Gia Bay station in the future periods and base period under scenario B2



	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	0.40	0.30	-0.38	-2.31	-1.88	-0.36	8.57	1.61	-0.41	-2.25	-0.89	-0.54
2040-2059	-1.11	-0.90	-1.73	-4.27	-3.25	-0.09	16.86	4.04	0.38	-3.27	-0.69	-0.52
2060-2079	-1.45	-0.97	-2.22	-5.46	-4.65	1.03	24.53	5.79	0.83	-4.24	-0.81	-0.81
2080-2100	-1.83	-1.10	-3.21	-6.77	-7.88	0.30	29.98	7.04	0.79	-5.80	-1.64	-1.15

Figure 4.13 Changes of flow on Upper Cau river basin under B2 scenario compared to base period (m^3/s)



	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	1.32	1.27	-1.61	-7.89	-3.17	-0.32	5.05	1.16	-0.39	-3.46	-1.74	-1.54
2040-2059	-3.70	-3.84	-7.23	-14.5	-5.49	-0.08	9.94	2.90	0.36	-5.02	-1.35	-1.48
2060-2079	-4.85	-4.11	-9.26	-18.6	-7.84	0.92	14.46	4.15	0.80	-6.51	-1.57	-2.30
2080-2099	-6.12	-4.69	-13.4	-23.1	-13.2	0.27	17.67	5.05	0.76	-8.90	-3.19	-3.24

Figure 4.14 Changes of flow on Upper Cau river basin under B2 scenario compared to base period (%)

4.3.1.2. Flood-season flow

The flow in flood season has the increasing trend on the entire Upper Cau river basin in the future under the CC scenario B2.

In the period of 2020-2039, the flood-season average flow is 109.3 m^3/s higher than that in the base period (108.4 m^3/s), and increases upto 112.4 m^3/s in the last century. So, compared to the flow of base period, it increases from 0.88 m^3/s (0.81%) to 4.07 m^3/s (3.76%).

In six flood-season months (May to October), the monthly average flow in June, July, August and September have an increasing trend. Especially, June and September have the flow in the period of 2080-2099 decreases a little compared to the previous period. July has the highest increasing change rate, from 5.05% upto 17.67% compared to the base period.

On the contrary, in May and October the monthly average flow has the decreasing tendency, from -3.17% down to -13.29% and from -3.46% down to -8.9% compared to the base period, respectively.

So, regarding to the flow distribution in year, the flood-season flow has the decreasing trend in the the beginning month of the flood season (May), then increasing strongly in the middle months of the season (from June to September), in the end month (October) it decreases steadily again.

Overall, the tendency of the monthly average flow changes in flood season on Upper Cau river basin is similar to the tendency of normal flood-season flow.

The average Runoff by periods in rainy season on Upper Cau river basin under scenario B2 is shown in Figure 4.15.

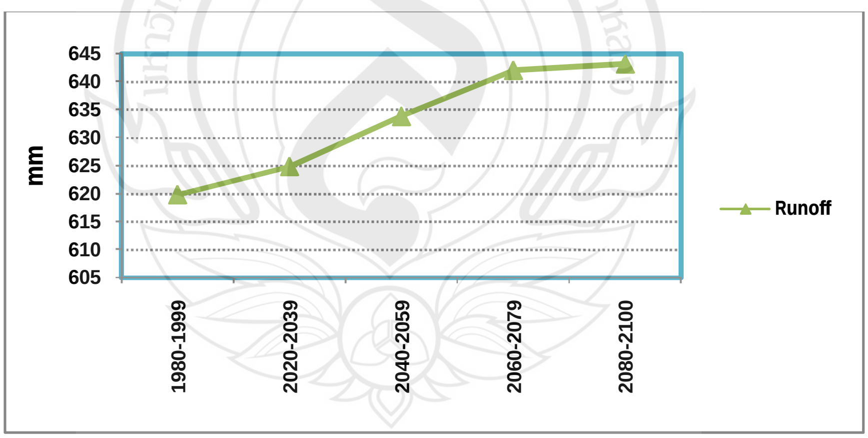


Figure 4.15 The Average Runoff by periods in rainy season on Upper Cau river basin under scenario B2

4.3.1.3. Dry-season flow

The flow in dry season has the decreasing trend in the entire Upper Cau river basin in the future under the CC scenario B2.

In the period of 2020-2039, the dry-season average flow is 31.7 m^3/s lower than that in the base period (32.2 m^3/s), and decreases down to 29.6 m^3/s in the last century. So, compared to the flow of base period, it decreases from -0.57 m^3/s (-1.78%) down to -2.62 m^3/s (-8.12%).

In all six dry-season months (January to April, November and December), the monthly average flow have a decreasing trend. Especially, November and December have the flow in the period of 2040-2059 increases a little compared to the previous period. April has the highest decreasing change rate, from -7.89% down to -23.11% compared to the base period.

So, regarding to the flow distribution in year, the dry-season flow has the decreasing trend from the middle months of the dry season (January, February) and decreases strongest in the end month (April), the beginning months have the inconsiderably decreasing rate.

Overall, the tendency of the monthly average flow changes in dry season on Upper Cau river basin is similar to the tendency of normal dry-season flow.

The average Runoff by periods in dry season on Upper Cau river basin under scenario B2 is shown in Figure 4.16.

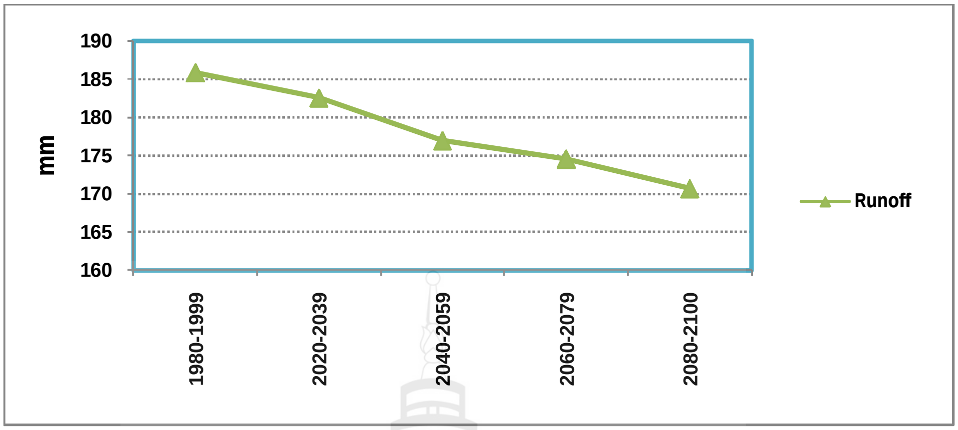


Figure 4.16 The average Runoff by periods in dry season on Upper Cau river basin under scenario B2

Finally, the changes rate of the annual average, flood-season and dry-season flow compared to the base period at Gia Bay station under the CC scenario B2 is presented in Figure 4.17.

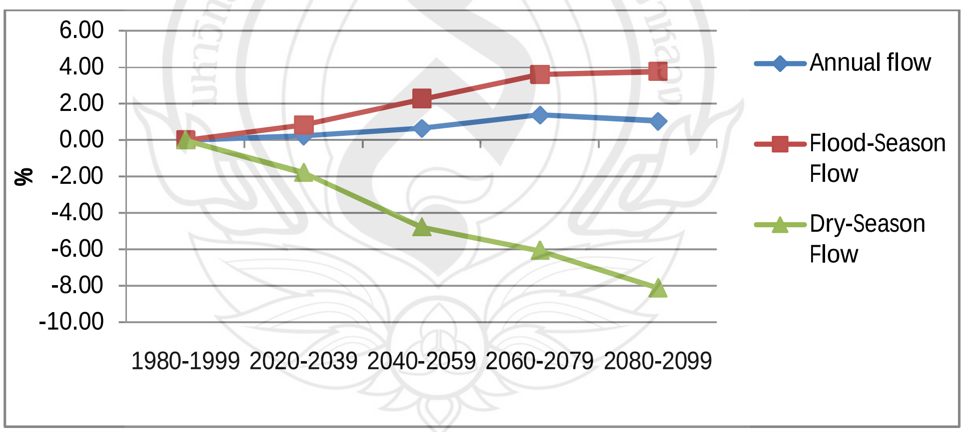


Figure 4.17 The changes rate of the annual average, flood-season and dry-season flow compared to the base period at Gia Bay station under the CC scenario B2

4.3.2 Soil loss changes over time at Gia Bay station

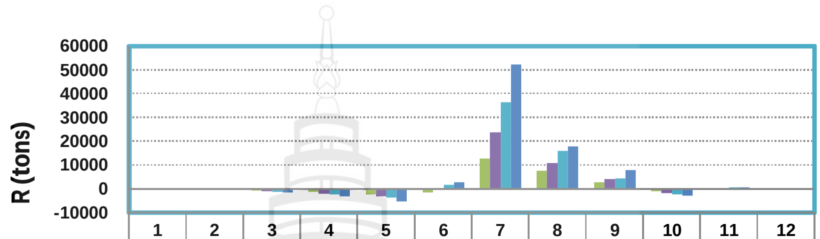
4.3.2.1 Annual erosion

The total annual soil loss (tons) at Gia Bay station tends to increase steadily compared to the base under the CC scenario B2. Compared to the base period, the average soil loss at Gia Bay station increases by 16642 tons (6.2%) in period of 2020-2039 and goes upward to 68951 tons (25.5%) in the last period of the century.

Table 4.10 The annual and monthly average soil loss by periods under scenario B2 at Gia Bay station (tons)

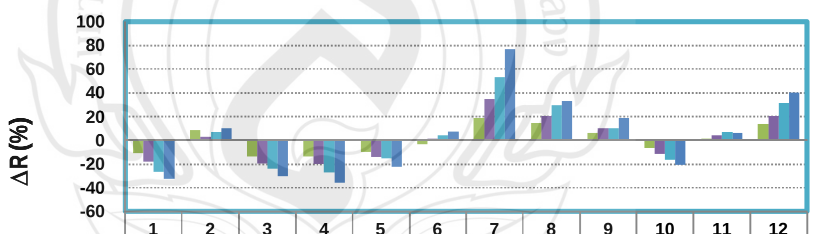
Period	1	2	3	4	5	6	7	8	9	10	11	12	Total	Flood season	Dry season
1980-1999	1008	1214	5075	9131	24010	40821	68353	53485	42504	14391	9386	1004	270381	243564	26818
2020-2039	900	1316	4382	7887	21647	39398	80975	61077	45301	13461	9538	1143	287023	261858	25165
2040-2059	826	1253	4095	7305	20719	41257	92213	64540	46638	12787	9778	1211	302621	278153	24468
2060-2079	741	1297	3885	6674	20362	42494	104923	69433	46965	12004	10010	1324	320112	296181	23931
2080-2099	677	1341	3551	5888	18782	43780	120641	71341	50523	11430	9972	1407	339332	316497	22835

Figure 4.18 and 4.19 presents the changes of average soil loss (tons) and its changes rate (%) by periods compared to the base period under scenario B2 at Gia Bay station on Upper Cau river basin.



	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	-108	102	-693	-124	-236	-142	1262	7592	2796	-930	152	139
2040-2059	-181	39	-980	-182	-329	436	2386	1105	4133	-160	392	206
2060-2079	-267	84	-119	-245	-364	1673	3657	1594	4461	-238	624	320
2080-2100	-331	127	-152	-324	-522	2959	5228	1785	8019	-296	585	403

Figure 4.18 The changes of average soil loss by periods compared to the base period under scenario B2 at Gia Bay station (tons)



	1	2	3	4	5	6	7	8	9	10	11	12
2020-2039	-10.7	8.4	-13.7	-13.6	-9.8	-3.5	18.5	14.2	6.6	-6.5	1.6	13.8
2040-2059	-18.0	3.2	-19.3	-20.0	-13.7	1.1	34.9	20.7	9.7	-11.1	4.2	20.5
2060-2079	-26.5	6.9	-23.4	-26.9	-15.2	4.1	53.5	29.8	10.5	-16.6	6.6	31.9
2080-2099	-32.8	10.5	-30.0	-35.5	-21.8	7.2	76.5	33.4	18.9	-20.6	6.2	40.1

Figure 4.19 The changes rate of average soil loss by periods compared to the base period under scenario B2 at Gia Bay station (%)

The annual average soil loss and rainfall by periods at Gia Bay station under CC scenario B2 on Upper Cau river basin is shown in Figures 4.20. This shows a close correlation between changes in precipitation variability and changes in monthly soil loss. An increase in precipitation variability was often accompanied by an increase in soil loss, and vice versa. These results indicate that soil loss prediction is sensitive to changes in precipitation variability.

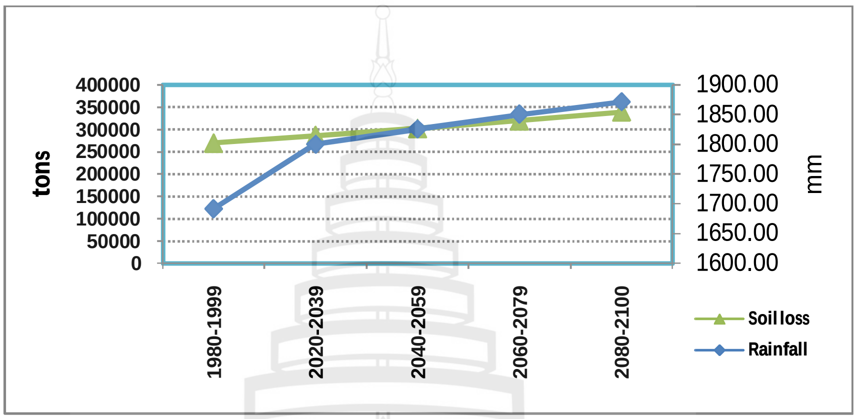


Figure 4.20 The annual average soil loss and rainfall by periods at Gia Bay station under scenario B2

4.3.2.2 Flood-season erosion

The total annual soil loss (tons) in flood season at Gia Bay station tends to increase steadily compared to the base under the CC scenario B2.

Compared to the base period, the changes of average soil loss in flood season at Gia Bay station increases by 18249 tons (7.5%) in period of 2020-2039 upto 72933 tons (29.9%) in the last period of the century (2080-2099).

Figure 4.21 shows the average soil loss (tons) in flood season by periods at Gia Bay station under the CC scenario B2 on Upper Cau river basin.

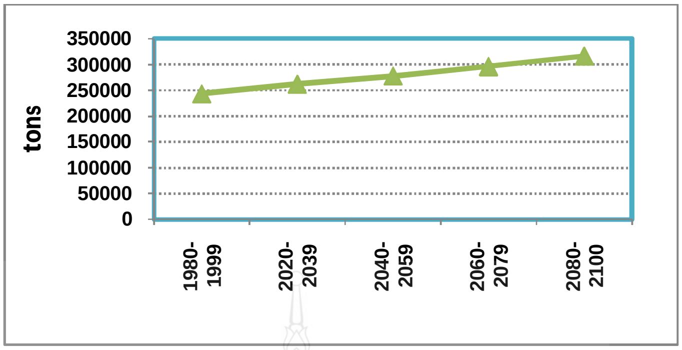


Figure 4.21 The average soil loss in flood season by periods at Gia Bay station under scenario B2

4.3.2.3 Dry-season erosion

The total annual soil loss (tons) in dry season at Gia Bay station tends to decrease steadily compared to the base under the CC scenario B2.

Compared to the base period, the changes of average soil loss in dry season at Gia Bay station decreases by -1652 tons (-6.2%) in period of 2020-2039 down to -3982 tons (-14.8%) in the last period of the century (2080-2099).

Figure 4.22 shows the average soil loss (tons) in dry season by periods at Gia Bay station under the CC scenario B2 on Upper Cau river basin.

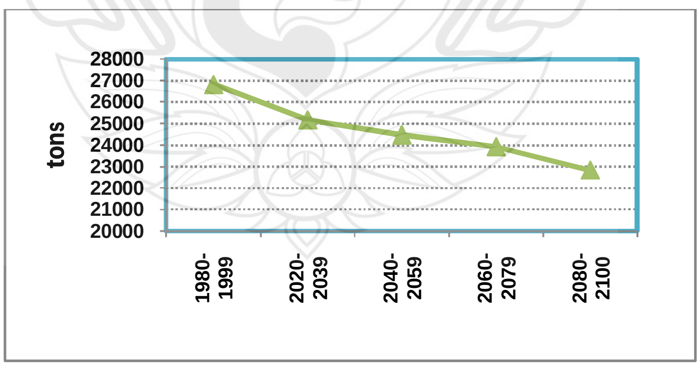


Figure 4.22 The average soil loss in dry season by periods at Gia Bay station under scenario B2

4.3.3 Soil loss distribution in sub-basins

4.3.3.1 Annual soil loss

Based on the classification regulations of erosion status according to Vietnam standard (Vietnam soil quality, 1995), the study area could be divided into 4 erosion levels in the period of 1980- 1999 (Table 4.11).

Table 4.11 Erosion classification (1980- 1999)

No.	Erosion level	Soil loss (tons/ha/year)	Area (ha)	Percentage of area (%)
1	Level I	0 – 10	173473.8	61.2
2	Level II	10 – 50	106260.9	37.5
3	Level III	50 – 200	2673.0	0.9
4	Level IV	> 200	1103.2	0.4
Total			**283510.9**	**100**

The results of erosion classification of Upper Cau river basin show that the erosion status of the basin has uneven areas among erosion levels. The erosion level I accounts for the most area with 61.2% of the total, twice times compared to that of level II with 37.5%. Meanwhile, the erosion level III and IV in the basin only makes up 0.9% and 0.4%, respectively. The total soil loss is 1164.6 tons/ha/year.

Figure 4.23 shows the monthly soil loss in all subbasins on Upper Cau river basin in the period of 1980-1999. This map is suitable with the flood and dry seasons with high soil loss focusing much on July and August and decreasing gradually in the other months of dry season in year.

Figure 4.24 represents the annual soil loss in 35 subbasins on Upper Cau river basin in the period of 1980-1999. From the Figure, it can be seen that subbasins having soil loss of lower than 10 tons/ha/year are located in South-West and North-East areas of Upper Cau river basin, accounting for most of the basin area. The slope in the South-West area is ranging from only 0^0 to 3^0 and rock exists prevalently here, leading to the erosion situation of the area occurs not so severe. On the other hand, nearly one third of the area looses 10 to 50 tons of soil per ha every year. These subbasins focus on the North-West, middle and south areas. In which, the North-West area has the quite high slope (>25^0), one of the reason making this much mount of soil loss. Especially, the remaining small areas have severer soil loss status. Only subbasin 17 and 33 have higher soil loss amount (50-200 tons/ha/year) meanwhile subbasin 4 and 35 have the highest erosion cases in the entire basin with soil loss amount is more than 200 tons/ha/year. In general, the results reflect relatively the erosion levels compared to the topography and land slope of two provinces Bac Kan and Thai Nguyen with hills, where is tranferred gradually between the plains and the mountainous terrain.

Figure 4.25 shows the annual soil loss in subbasins on Upper Cau river basin in the four periods of the future: 2020-2039, 2040-2059, 2060-2079, 2080-2099. Compared to the base period 1980-1999, the erosion status of the Upper Cau river basin has the increasing trend with more annual soil loss. Particularly, in the period of 2020-2039, the subbasin 23 moves from the level 10-50 to 50-200 tons/ha/year. The other subbasins have inconsiderably increasing soil loss amount. However, in the next two periods, subbasin 28 and 8 in turns go upward in erosion level, the same with subbasin 23, respectively. It proves that the erosion in the future under the impacts of CC severer by time. This is understandable because of increasing trend of rainfall and flow which are the factors influencing on erosion.

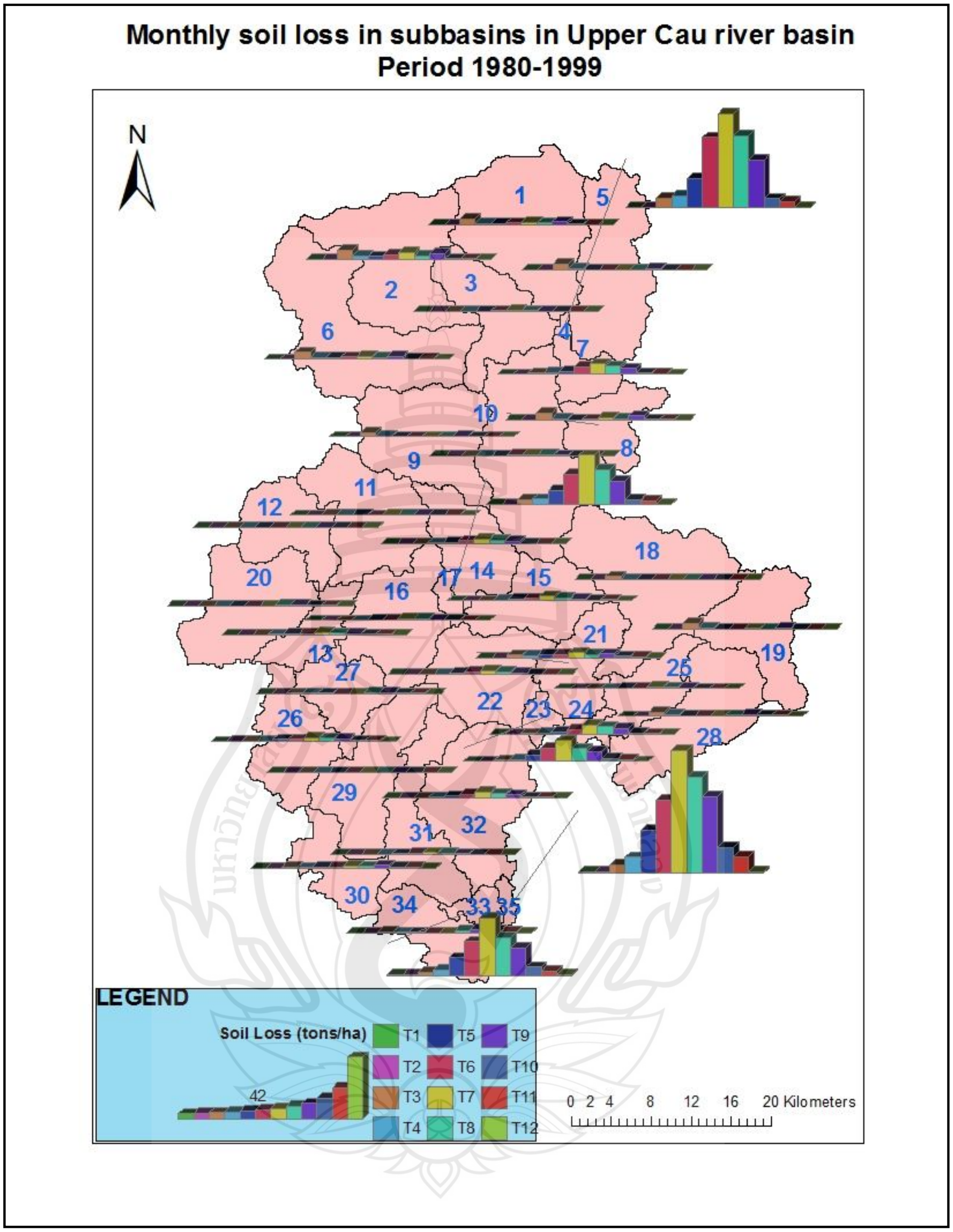


Figure 4.23 The monthly soil loss in subbasins on Upper Cau river basin (period 1980-1999)

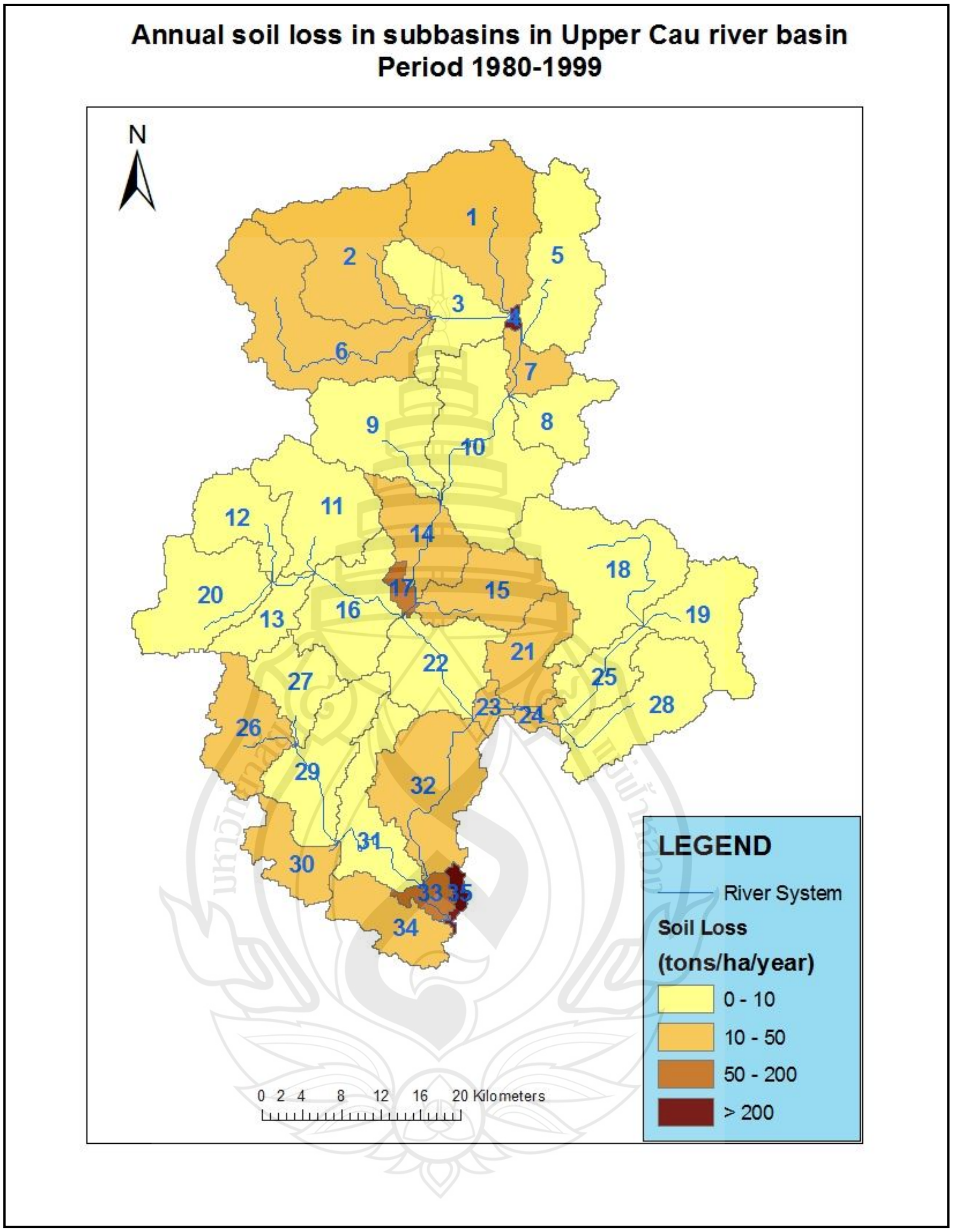


Figure 4.24 The annual soil loss in subbasins on Upper Cau river basin (period 1980-1999)

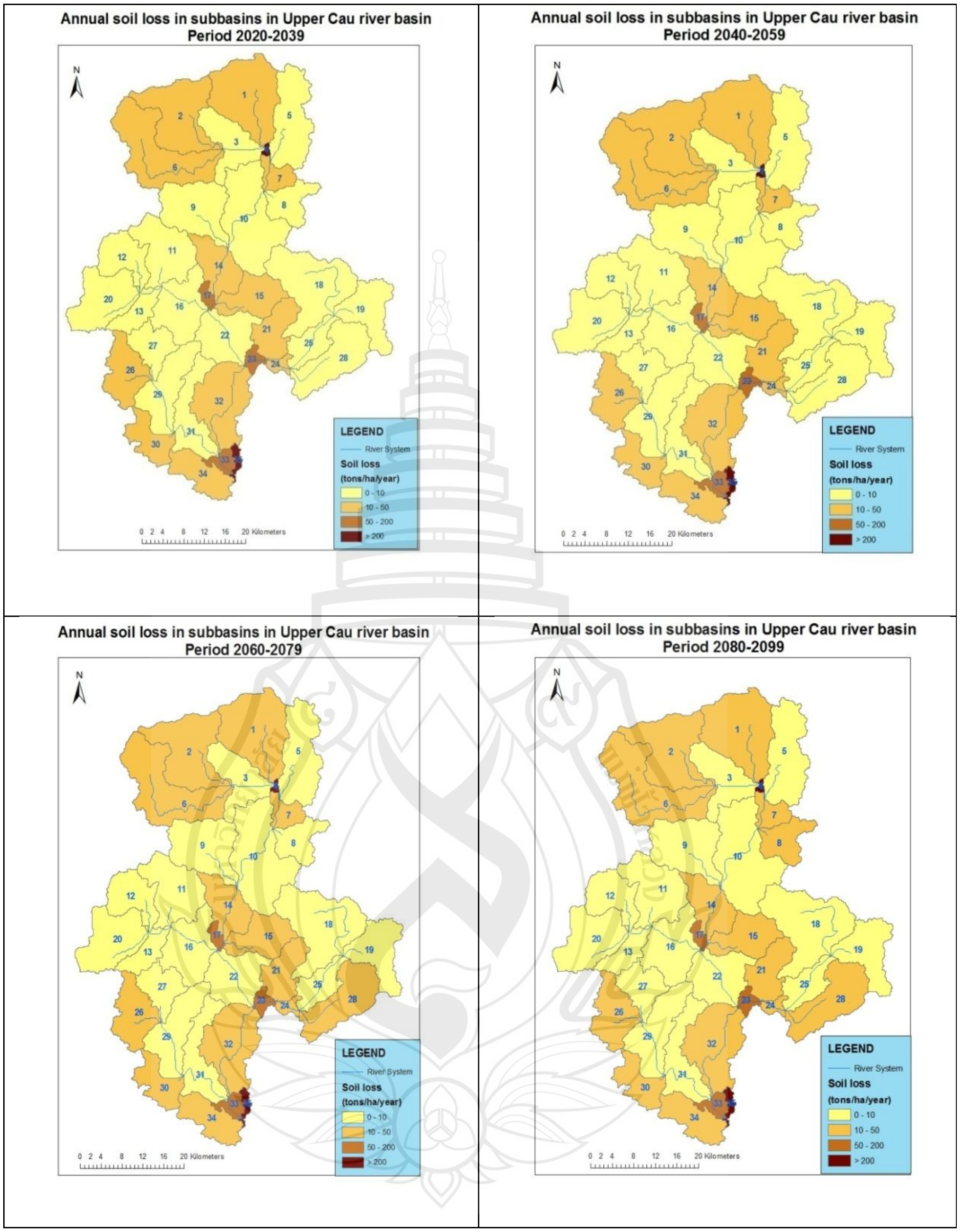


Figure 4.25 The annual soil loss in subbasins on Upper Cau river basin by periods in the future

4.3.3.2 Flood-season Soil loss

Figure 4.26 indicates the soil loss in flood season in 35 subbasins on Upper Cau river basin of the present time - period 1980-1999 and Figure 4.27 shows that of the future.

From the two Figures, it can be seen that the erosion status in flood season of the basin under the impacts of CC has an increasing tendency, appropriate with increasing trend of rainfall and flow in the Upper Cau river basin in flood season.

In period of 2020-2039, in subbasin 15 and 30, the soil loss level moves from 0-10 to 10-50 tons/ha/year. In the next period, the subbasin 34 has the same situation. Likely, subbasin 1 in the period of 2060-2079 is similar meanwhile subbasin 23's soil loss amount goes upwards with the level from 10-50 to 50-200 tons/ha/year. And in the years of last period, 2080-2099, subbasin 6 also has higher level of erosion.

Percentage rate of flood-season soil loss in the future compared to base period is shown in Figure 4.28. It demonstrates the erosion status of the future periods under CC has higher level by time in flood season. The percentage values were calculated on the basis of the following equation:

$$A_{xy} = 100 * (B_{xy}-C_x)/C_x$$

In which:

A_{xy}: the percentage rate of flood-season soil loss in the future compared to base period (%)

x: each sub-basin → x= 1,2,…,34,35

y: each future period → y = 2020-2039, 2040-2059, 2060-2079, 2080-2099

B_{xy}: the total flood-season soil loss in each sub-basin, in each period of the future (tons)

C_x: the total flood-season soil loss in each sub-basin, in the base period of 1980-1999 (tons)

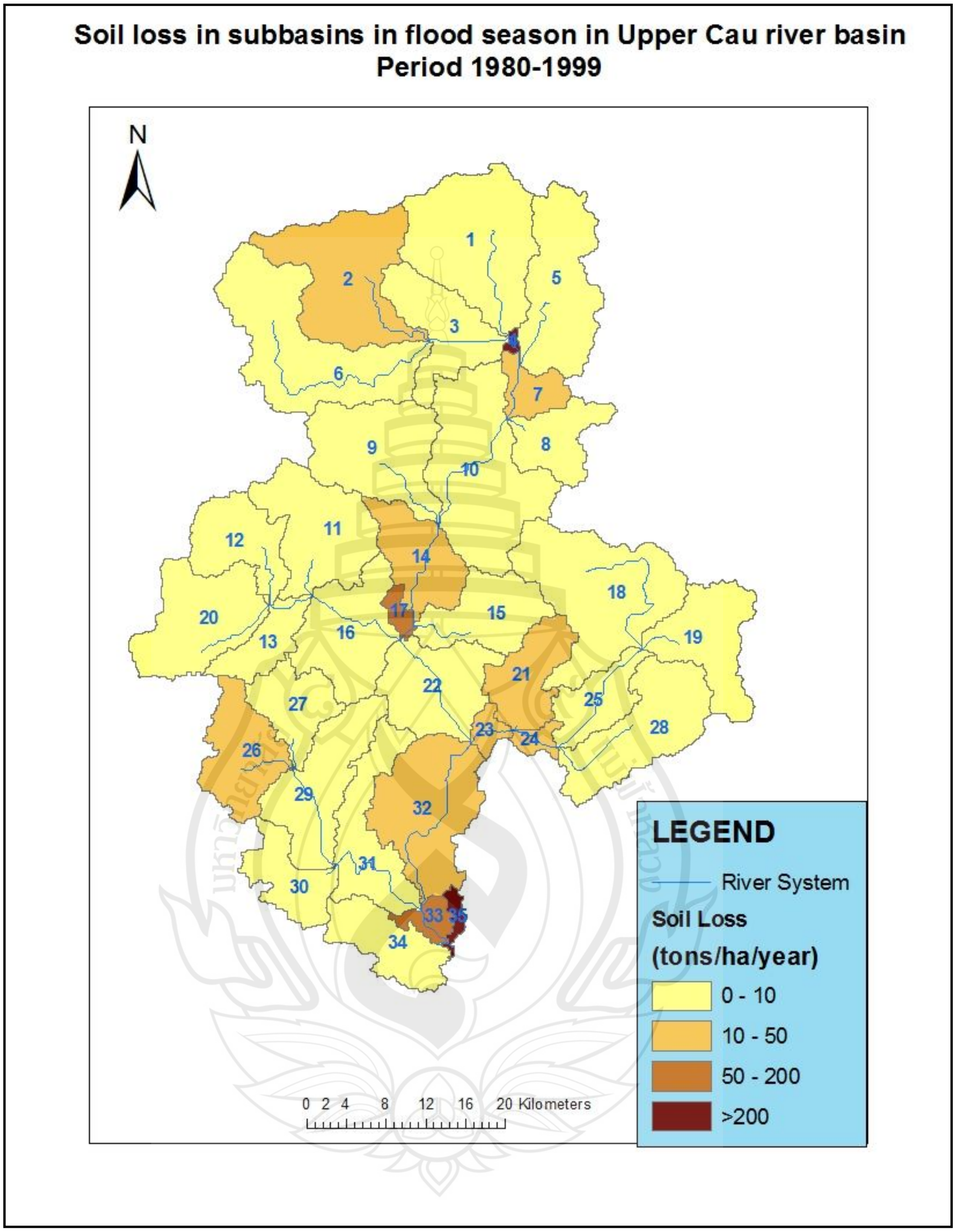


Figure 4.26 The soil loss in flood season in subbasins on Upper Cau river basin (period 1980-1999)

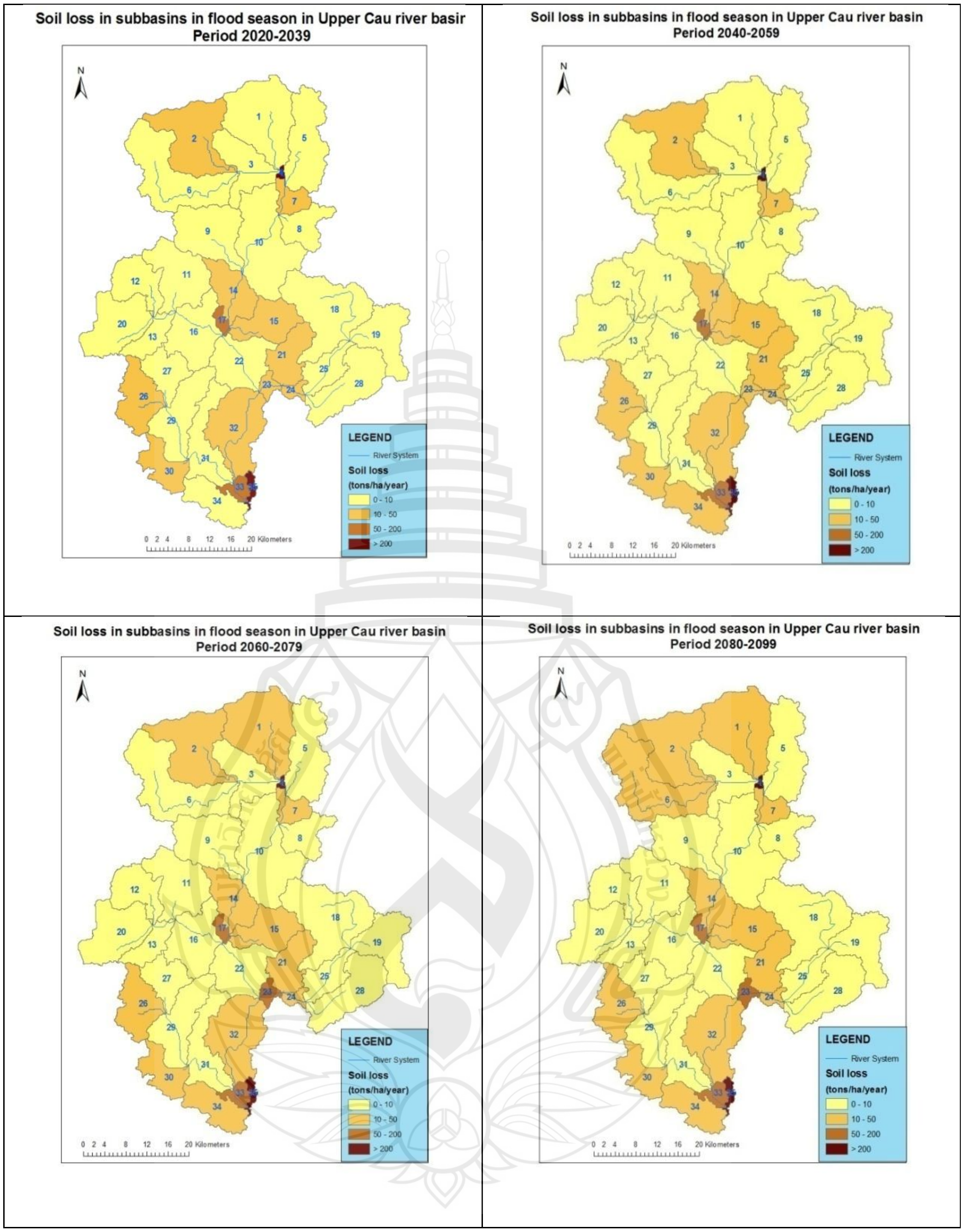


Figure 4.27 The soil loss in flood season in subbasins on Upper Cau river basin in by periods in the future

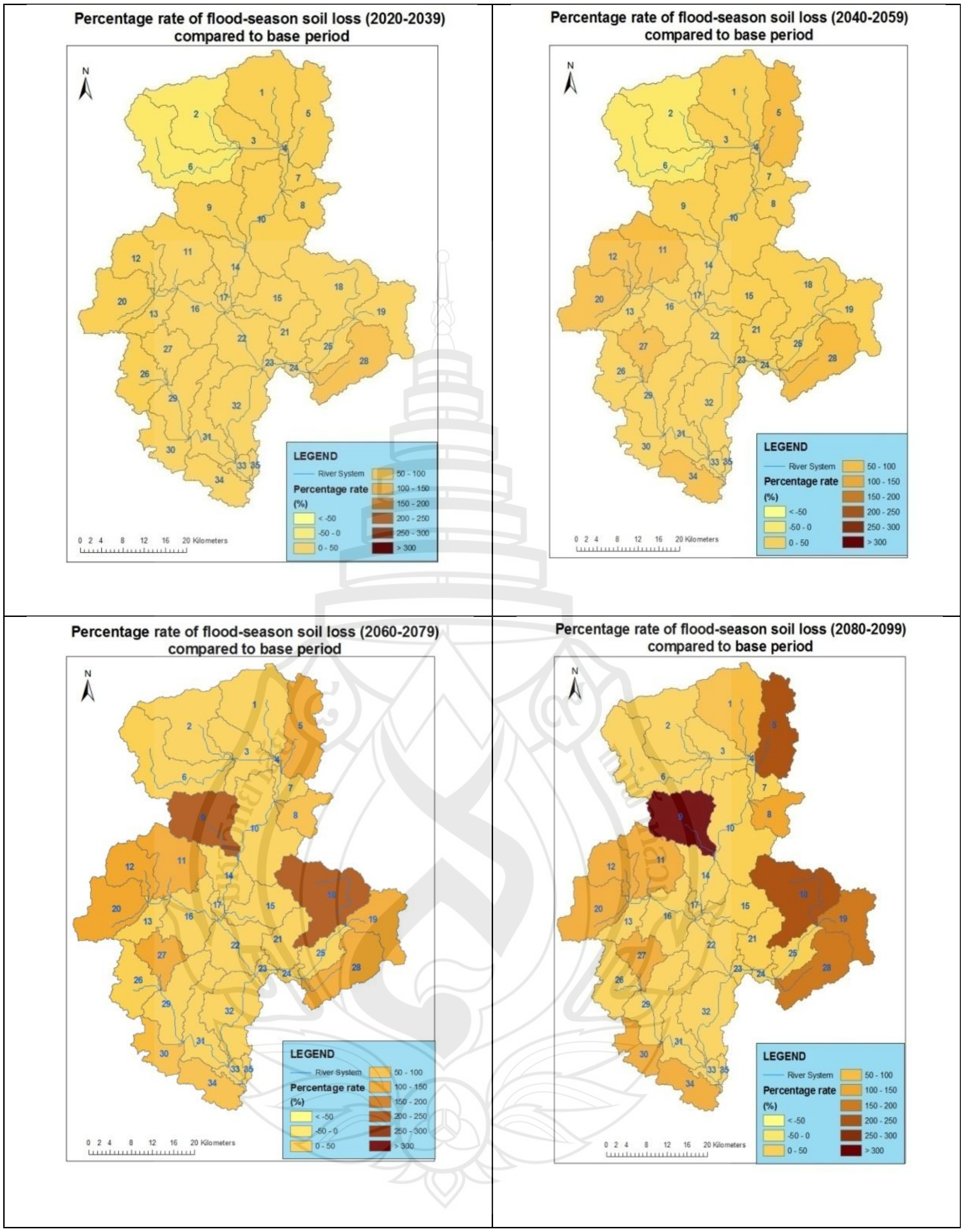


Figure 4.28 Percentage rate of flood-season soil loss in the future compared to base period

4.3.3.3 Dry season Soil loss

Figure 4.29 indicates the soil loss in dry season in 35 subbasins on Upper Cau river basin of the present time - period 1980-1999 and Figure 4.30 shows that of the future.

From the two Figures, it can be seen that the erosion status in dry season of the basin under the impacts of CC has a decreasing tendency, appropriate with decreasing trend of rainfall and flow in the Upper Cau river basin in dry season.

Compared to the period of 1980-1999, in the subbasin 17 of the four periods of the future, the soil loss level moves downwards from 10-50 to 0-10 tons/ha/year. The other subbasins have the insignificantly decreasing trend in erosion levels.

Percentage rate of dry -season soil loss in the future compared to base period is shown in Figure 4.31. It demonstrates the erosion status of the future periods under CC has lower level by time in dry season. The percentage values were calculated on the basis of the following equation:

$$A_{xy} = 100 * (B_{xy}-C_x)/C_x$$

In which:

A_{xy}: the percentage rate of dry -season soil loss in the future compared to base period (%)

x: each sub-basin → x= 1,2,…,34,35

y: each future period → y = 2020-2039, 2040-2059, 2060-2079, 2080-2099

B_{xy}: the total dry -season soil loss in each sub-basin, in each period of the future (tons)

C_x: the total dry -season soil loss in each sub-basin, in the base period of 1980-1999 (tons)

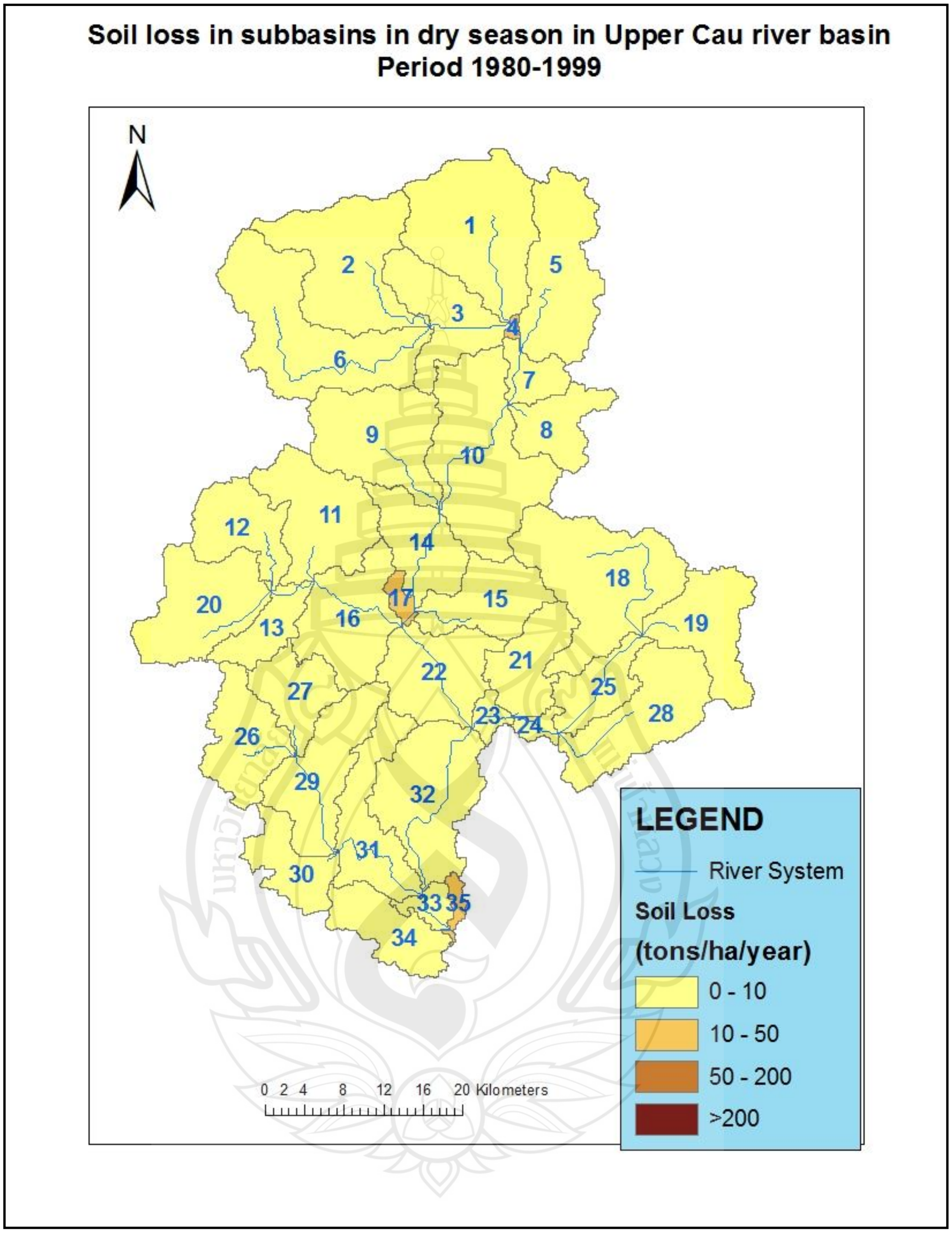


Figure 4.29 The soil loss in dry season in subbasins on Upper Cau river basin (period 1980-1999)

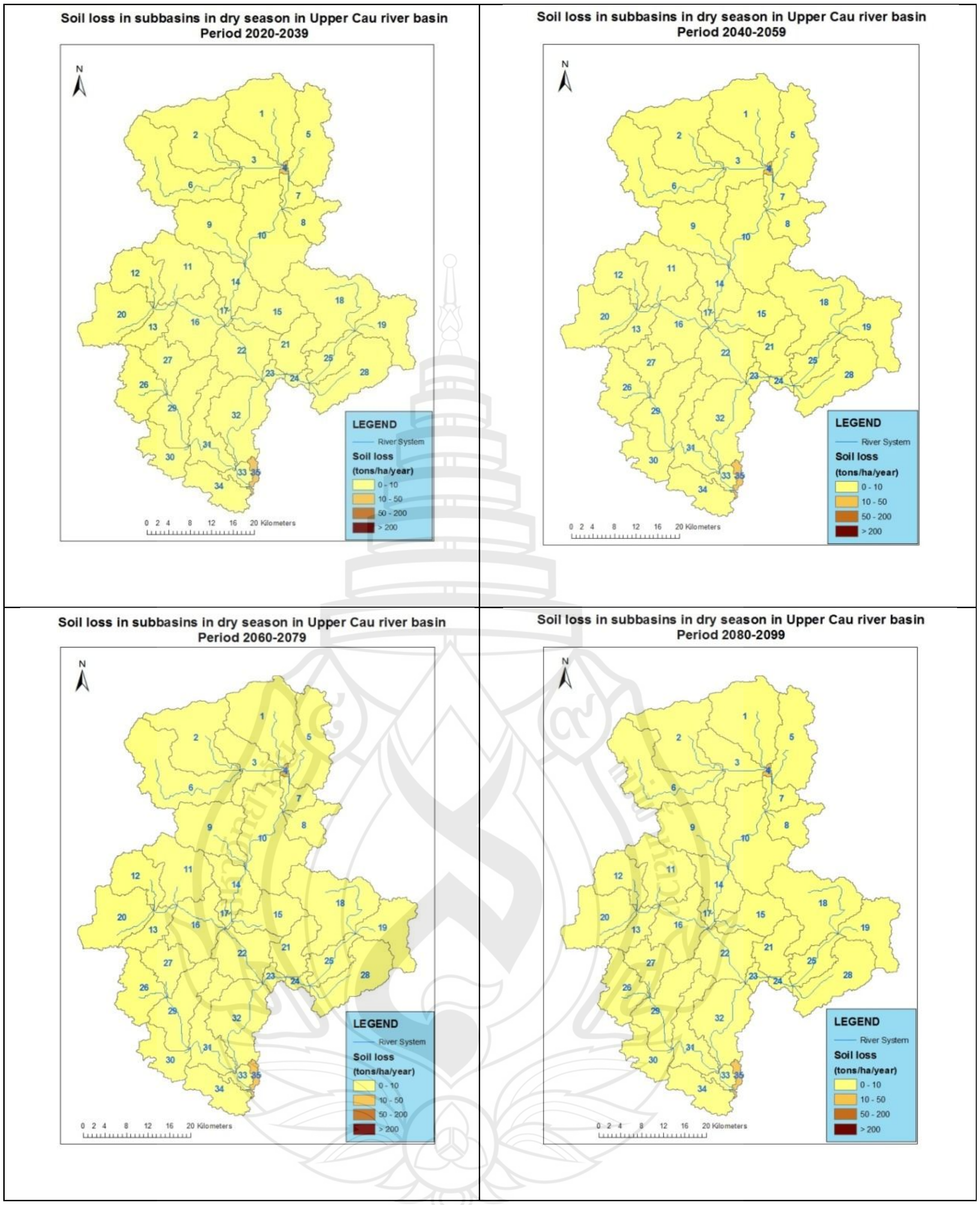


Figure 4.30 The soil loss in dry season in subbasins on Upper Cau river basin in by periods in the future

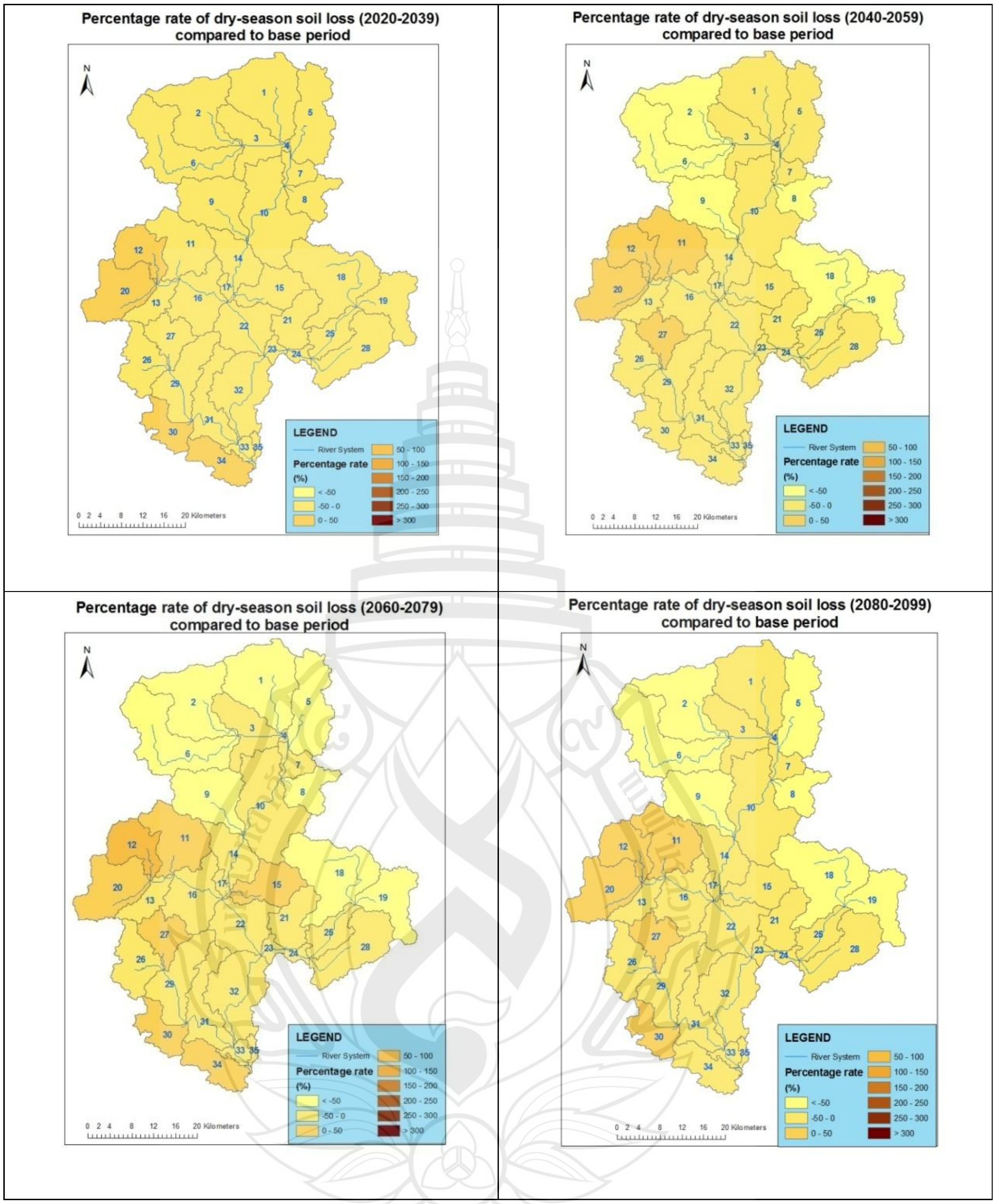


Figure 4.31 Percentage rate of dry-season soil loss in the future compared to base period

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Cau river basin is one of the basins that play significant socio-economic role in the North of Vietnam. The Upper Cau river basin restricted at Gia Bay station with the total area of 2,835 km^2 is located in Bac Kan and Thai Nguyen provinces. It is facing problems in Water resources that is at risk of degradation and depletion of quality as well as quantity especially in the context of CC. Moreover, due to territory and land cover characteristics, the basin has the possibility of having erosion. Therefore, the study focused the research on the current status of flow which is main subject and one of its consequences - soil erosion - with the impacts CC in the future would have on them.

SWAT model which was the helpful tool was applied to make the research on the flow regime and erosion process. Its input requirement data is quite a lot, including the land use map which is a very important factor. RS was utilized to consolidate the preciseness of the map. The study exported the residents area on Upper Cau river basin from Landsat image to combine with the surveyed Landuse map in 1993 to enhance the preciseness of data.

From the results, on Upper Cau river system, it was included that the total annual runoff tends to increase compared to the baseline under the CC scenario B2. The changes rate of the later periods is bigger than the previous ones, appropriate with the changing tendency of evaporation and rainfall which are the most important factors affecting on flow regime (rainfall increases much but evaporation increases less leading to annual runoff increase).

The impacts of CC on flow regime are presented apparently in flow variation in flood and dry season in future periods. The imbalance in the flow distribution in year is shown in the considerably increasing trend of flow in flood season and decreasing trend in dry season. Specifically, the flood-season flow has the decreasing trend in the beginning month (May), then strongly increasing in the middle months of the season (from June to September), and in the end month (October) it decreases steadily again. Meanwhile, the dry-season flow has the decreasing trend from the middle months of the dry season (January, February) and decreases strongest in the end month (April), the beginning months have the inconsiderably decreasing rate. It means that floods occur more frequently with larger amount of discharges in rainy season, while water shortage and drought would be more serious in dry season.

The change of flow affects many areas related to water resources, such as increases risk of degradation and depletion, water pollution; increases the level and scope of surface waters or groundwater aquifers that have saline intrusion; affecting mining operations, the use of water resources while water demand for socio-economic activities continues to increase.

Moreover, increasing in total annual runoff also affects the erosion status in the basin. It would in general increase the total annual sediment load (soil loss). At Gia Bay station on Upper Cau river basin, the total annual soil loss (tons) tends to increase steadily compared to the baseline under the CC scenario B2. Especially, in the flood season, greater variability in daily precipitation distribution led to increased occurrence of large storms and therefore greater stream discharge and soil loss, leading to at Gia Bay station, the soil loss has increasing trend. On the contrary, in dry season, it decreases gradually compared to the period of 1980-1999.

With regards to the erosion status classification of the base period (1980-1999) on Upper Cau river basin, the annual soil loss was divided into four erosion levels which are distributed in different areas. The erosion level I accounts for the most area of the total (more than half), followed by level II while level III and IV in the basin only occupy very small areas. This means that the erosion situation of the basin was not so severe in the base period. Thereby, the study established the maps of total current and potential soil loss process for Upper Cau river basin under the CC scenario B2. Compared to the base period 1980-1999, the potential erosion of the basin in the future has the increasing trend with more annual soil loss, proving that the erosion under the impacts of CC severer over time. This is understandable because of increasing trend of rainfall and flow which are the factors influencing significantly on erosion. The sediment load changes differently between dry and flood seasons. The flood-season soil loss increases while the dry-season one decreases in CC scenario B2. Moreover, high soil loss focuses much on July and August and decreases gradually in the other months of dry season in year. This is appropriate with increasing tendency of flow and rainfall in flood season and vice versa in dry season in a year. Sediment load in the whole flood season can be more than twenty times than that in the dry season months in one sub-basin in the last century.

The effect of CC on soil erosion is also not homogeneous throughout the basin. The soil loss distribution is different among 35 sub-basins. Significant impacts are observed in the sub-basin 4, 17, 33, 35 where are converged many tributaries from the upstream. Because much rainfall in flood season promotes erosion and infertile soil, steep slopes (> 25^0) accounts for a high proportion, the eroded soil materials are mainly not deposited but follow to the rivers and streams.

The Upper Cau river basin has the total current soil loss of 1164.6 tons/ha/year (1980-1999) and potential soil loss of 1371.83 tons/ha/year (2080-2099). The difference of the two values shows the impacts of CC on erosion.

Through the analysis, the results of the study revealed that under the CC scenario B2, the climate trends on Upper Cau river basin are leading to severer conditions for runoff generation as well as erosion status due to an increase in evaporation and rainfall in the period of 2020-2100. Additionally, applying SWAT model and GIS technique is fairly accurate helping managers easily identify severity levels of flow regime and areas having high possibility of soil erosion in the basin in the context of CC, thereby, making appropriate measures in the future in order to limit the effects of these processes to daily life and the production and business activities of the local people.

5.2 Recommendations

Based on the results of the study stated in Chapter 4, a number of policy management for the authorities on Upper Cau river basin would be proposed as follows:

5.2.1 Proposed solutions for flood prevention

5.2.1.1 Construction solutions

1. Upstream of Cau river through Bac Kan province

In order to prevent flood for Bac Kan town, it is urgently need to build Nam Cat reservoir at Nam Cat stream of Na Pen village, Duong Quang commune - Bac Kan town. At the same time, deploying embankments on both sides of Cau river in the town area and surrounding areas is to prevent banks'erosion, protect livelihoods, protect historical monuments and landscape for the town. It is necessary to construct shore protection embankments at several key positions on the mainstream river. In Bach Thong district, it is needed to build 13 embankment sections: Na Xon residential area (Cam Giang), Na Phai, Pac Cap, Na Me (Quan Binh), Na Giao, Na Phai (Phuong Linh), Na Bap (Ha Vi), Na Xom (Cam Giang); Embankments against erosion in some fields in Quang Thuan - Bach Thong communes, such as fields of Na Leng, Na Dieu, Na Mon; Embankments in Khuoi Nhau in Binh Thanh commune, Na Mo in Yen Dinh commune, Choc Toong in Cho Moi district.

Bac Kan often occurs flash floods, thus flash flood prevention is an urgent and hard task due to the characteristics of flash flood is occurring on a small scale and often in the remote regions. In order to prevent flash floods, there are some solutions, such as constructing small reservoirs for flood control in the area that flash floods often occur; dredging the flood escape route; constructing dikes, walls obstructed flash floods; constructing dikes for blocking rocks at the mouth of the stream; classifying flood.

2. Middle part of Cau river through Thai Nguyen province

In addition to above flash-flood prevention measures for upstream, problems of flood prevention for Thai Nguyen is nessary, especially to ensure the safety of Thai Nguyen City. In the province, two main dike lines have formed which are the one on the right hand side of Cau river and Cong river dike (in the lower part of Cau river basin) with a total length of 53.6 km of the dike works consisting of 22 sluices and 5 embankment.

On the Cau River basin, Thai Nguyen province has many reservoirs having most flood prevention capacity: Nui Coc Lake, Bao Linh Lake, Go Mieu lake, the other small and medium reservoirs (Doan Uy lake, Phu Xuyen lake, Khoi Ky lake (in Dai Tu district), Quan Che lake in Vo Nhai district, Genh Che lake in Song Cong town, Suoi Lanh lake in Pho Yen district, Dong Xieng lake in Phu Luong district). These reservoirs has a positive effect against the flood, however, to ensure more safety for Thai Nguyen city and the other areas, it should be considered in the future the plan of building Van Lang reservoir or upgrading Cau river's dikes. In terms of the integrated use of water resources, the construction of reservoirs is more beneficial than upgrading dikes, however, it should be based on economic efficiency analysis, environmental impact and impact on the social life of local residents to make appropriate plans.

To limit inundation when heavy rains occurs in the area of indigestion of flow, it is needed to upgrade the system of pump stations, repairs, dredging, building new channels frequently to make them be resolved as designed discharge.

Completing the drainage system, rehabilitating, constructing pump stations are in order to resolve inundation for areas suffering usually flooding.

5.2.1.2 Non-Construction solutions

Planting and protecting upstream forest to prevent flooding and flash floods.

Organizing of effective management and exploitation of flood prevention measures.

Establishing organizations supporting disaster management.

Organizating of dyke protection.

Enhancing capacity of flood warning and forecasting.

Putting knowledge of disaster into programs for high school students.

Completng system of legal documents on the prevention of floods, flash floods.

Mapping in areas where occur flash floods and risk of flash floods.

Evacuating from the area of flash floods.

5.2.2 Proposed solutions for drought prevention

5.2.2.1 Solutions for water resources protection before drought occurs

Developing and implementing effectively monitoring system to detect drought as a major component of hydro-meteorological information systems.

Improving conditions for operation, maintaining and managinge water-supply systems mainly to controll the water loss in operation.

Establishing a policy of water division to implement during the drought occurs, in which it must be considered all aspects of socio-economic and environment of water use restrictions.

Planning for water increase may be reached in drought time, including the reuse of waste water, use of resources and should be noted that the water must be stored in stored capacity before drought happens.

Controlling and planning so as to obtain a large number of ground water to increase water resources during the drought.

Monitoring closely water resources, especially storing and operating water in reservoirs to minimize the impacts of reduced water in time of drought.

Deploying early drought prevention works, field-combat pump stations, organizing to take early the water for storing in the canals, ponds, marshes, sunken fields.

Reviewing the area of water shortage to plan the plant restructuring.

Developing detailed drought prevention plan into each clue pump station, preparing human and material resources and the specific measures to be proactive in cases of water river level goes down to the lowest.

Developing techniques and practicing to implement into the last water users helping reduce the water use demand and waste water control under conditions of reducing water.

Developing the institutional conditions for the preparation and management before the drought occurs, including the deployment over time of mitigation measures due to drought.

Constructing water price and financial assistance as well as having sanctions to reduce the consumption and water use and avoid water waste and loss, including the control of water quality degradation.

Increasing awareness of the community about socio-economic, social and environmental value of water as well as implementing mitigation measures to limit drought damage.

Strengthening the steering and supervision operation, promptly resolving arising problems in the implementation process.

5.2.2.2 Solutions for mitigating damage of drought after drought occurs

Exploiting the drought monitoring system to supervise the situation of the drought, to provide information for decision makers and water users.

Implementing of changes of the principles of operation management of water and groundwater reservoirs in accordance with the drought prevention.

Implementating the policies of water leading and water resources allocation required for all water users.

Using water sparingly and strengthening measures of water storage into field surface, river systems, inland canals supplying water to generate resources for the pump stations in the system.

5.2.3 Proposed solutions for soil protection

The role and effects of the surface land use and land cover on soil protection should be increasingly concerned. It is necessary to take measures to protect the land cover such as planting and protecting forests, using crop residue to cover the surface land, growing plants and trees (tea, shrubs, grass), reasonable crop cultivation, etc. Especially in flood season, in areas with steep slopes such as southern and northern part of Bach Thong district, highly potential erosion such as Dong Hy, south-west part of Vo Nhai, southern part of Dinh Hoa, northern part of Dai Tu districts, soil protection should be much more focused on. In the future, the concentration of soil protection should be particularly put on the eastern and north-western part of the Upper Cau river basin. Particularly, in Thai Nguyen province, large hill land area is the potential for the commodity development of industrial trees, fruits-eaten plants. However, the upstream forest of the province has been still destroying seriously. This fact is required by the authorities in the province to do surveys, strictly handle by law the individuals and organizations in violation of the provisions of the management and protection of forests. Also, it can be reduced tillage where possible, rotate crops and recycle organic residues back to the soil. With the formation of many sub-climates, Bac Kan province has the strength of structural transformation of plants and animals. This will enhance soil organic matter levels, help reduce soil compaction, and promote carbon sequestration in soil (which helps counteract atmospheric change due to greenhouse gas emissions).

Additionally, some other solutions would be suggested such as propagating to enhance public awareness of the impacts of CC on soil resources; controlling and minimizing soil erosion by employing practices designed to prevent wind and water from transporting soils away, and/or reduce physical and chemical degradation soil; adopting water-conserving strategies as appropriate including new irrigation techniques, mulching, soil moisture monitoring and irrigation scheduling; raising livestock with access to pasture/range when possible, and system of rotational grazing to prevent overgrazing and erosion.

5.3 Recommendations for further studies

Some specific recommendations for further studies in the future are as follows:

Further studies should do the field survey thoroughly for checking the real situation of flow and erosion on Upper Cau river basin. Thereby, there would be some pictures and testimonies for the results of the study.

Further studies should focus more deeply on RS and collect more other satellites data to compare images in order to consolidate the preciseness of the land use map. It might be found out the most typical year of satellites images for land use map in the base period (1980-1999).

Further studies should collect more meteorological and hydrological data from many other stations around Upper Cau river basin to enhance the results' accuracy.

The study stopped researching on sediment yield (water quality) and water discharge (water quantity). In order to draw a comprehensive picture of Water resources on the study area, it should be studied further on the other factors of water quality such as COD, BOD, NO_3, etc as well as water demand and water balance.

Soil erosion research should be studied based on the basin systems in general (from small to large). This will have proper assessment of soil loss from steep slopes, the distribution in the lowlands and the impact on other ecosystems, especially water. For the case study of Upper Cau river basin, it is necessary for further study in the whole Cau river basin, or even much bigger as Hong – Thai Binh river basin and the Northern part of Vietnam. In addition, soil erosion is a long process which takes place with the different time and intensity depending on many factors, in which the factor of rainfall plays a decisive role. Therefore, the assessment of erosion is needed to take enough field survey and data including sediment discharge which is the most important data for researching on erosion. However, erosion data in Vietnam is still rare and mostly only found from some major huge projects. Therefore, further studies would need much more funds for getting the data for bigger study area.

Further studies should focus on adjusting the model as long as a HRU's area would be smaller (around $1km^2$) to make the results in more details.

The future studies should take land use map into consideration in a dynamic way. Because this study took land use map 1993 as a given data although the author knew that land use map would be changed over time.

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APPENDICES

APPENDIX A

OVERVIEW OF SWAT MODEL

SWAT Model is a physical model developed from the early of 1990s by Dr. Jeff Arnold at the United State Department of Agriculture - Agricultural Research Service (USDA – ARS). SWAT is a river basin or watershed scale model developed to predict the impact of land management practices on water, sediment, and agriculture chemical yields in large, complex watersheds with varying soils, land use and management conditions over long periods of time. The model is process-based, computationally efficient, uses readily available inputs and capable of continuous simulation over long periods. SWAT is based on modern GIS tools, in particular the model can simulate the watershed based on DEM.

1. SWAT Model Structure

SWAT simulates hydrological processes taking place in the basin. Major hydrological processes that can be simulated by the model include evapotranspiration (ET), surface runoff, infiltration, percolation, shallow aquifer and deep aquifer flow, and channel routing (Arnold et al., 1998). Simulation of watershed hydrology is separated into:

1.1 Land phase (or basin phase) of the hydrological cycle: controls the amount of water, sediment loadings to the main channel in each basin

1.1.1 The land surface face

Water balance is the driving force behind all the processes in SWAT because it impacts plant growth and the movement of sediments, nutrients, pesticides, and pathogens. Hydrological cycle is described in the SWAT model based on the water balance equation as follows:

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

In which:

SW_t : The total amount of water at the end of the calculation period (mm)

SW_o : The total amount of initial water on day i (mm)

t : time (day)

R_{day} : Total rainfall on day i (mm)

Q_{surf} : Total amount of surface water on day i (mm)

E_a : The amount of evaporation on day i (mm)

W_{seep} : The amount of water going into the aquifer on day i (mm)

Q_{gw} : The amount of regression water on day i (mm)

1. The climatic factors

The climatic factors of the basin provide input data of the model to control water balance and determine the relationship among the different components of the hydrological cycle. The climate variables used in the SWAT model include: daily rainfall, max air temperature, min air temperature, the solar radiation, wind speed and relative humidity. The data are taken from the meteorological stations.

2. The hydrological factors

When rain falls, it could be blocked in the leaves layer or falling down to the ground. Water moves in a relatively fast way towards channels creating the direct flow. The amount of water that penetrates into soil will contribute to groundwater flow. Hydrological calculation in the model consists of the following components: computing groundwater flow, computing losses, computing surface runoff, computing in the reservoir, computing in the channels.

1.1.2 Soil erosion due to rainfall and flow

Surface erosion is mainly caused by rainfall and flow. SWAT uses Modified Universal Soil Loss Equation (MUSLE) which was developed on the basis of the USLE equation to estimate soil erosion and sediment caused by rainfall and runoff. Because sediment yield prediction is improved runoff is a function of antecedent moisture condition as well as rainfall energy. In MUSLE equation, rain-induced erosion coefficient is replaced by the flow-induced erosion coefficient. The erosion- calculated MUSLE equation is written as follows:

$$sed = 11,8\left(Q_{surf} \cdot q_{peak} \cdot area_{hru}\right)^{0,56} \cdot K_{USLE} \cdot LS_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot CFRG$$

In which:

Sed : The amount of soil eroded during the calculated period of 1 day [tons]

Q_{surf} : Total amount of surface runoff (mm)

q_{peak} : flood-peak discharge (m^3/s)

$area_{hru}$: area of one unit (ha)

K_{USLE} : coefficient of soil erosion [t.h/(ha.N)]

L_{USLE} : Coefficient of erosion due to the impact of slope length [-]

S_{USLE} : Coefficient of erosion due to slope [-]

C_{USLE} : coefficient of the impact of crop on soil erosion [-]

P_{USLE} : coefficient of the impact of farming practices on soil erosion [-]

CFRG : raw coefficient

Moreover, there are some other components processes of the land phase, such as: Groundwater Phase - The movement of water in soil; Elements of nutrients and plant protection products; Water quality parameters; Plantation coverage, plants; The operations of management.

1.2 Instream or routing phase – Computing process of hydrological cycle (the movement of water, sediments, etc., through the channel network of the watershed to the outlet)

This is the phase in which SWAT determines the movement of water, sediment, nutrients and plant protection chemicals through the channel network of the watershed to the outlet. In addition to calculating the discharge, the model also describes the chemical changes in the channel.

- Computing in the river: can be divided into four components: water, sediment, nutrients and organic chemicals.

- Computing in reservoirs: The water balance for the reservoirs includes incoming flow, outgoing runoff, surface precipitation, evaporation, seepage through the lake bottom and water-division works.

The instream or routing phase can be divided into some other components, such as the calculating process of flow; the calculating process of sediment flow; the calculating process of nutrients substances; the calculating process of plant-protection substances; the calculating process in reservoirs.

2. SWAT Calculation Steps

2.1 Enter topographic map in the form of DEM

2.2 Define the basin and stream network.

2.3 Divide the basin into sub-basins and calculate their parameters such as numerical orders, slopes, widths, areas, etc.

2.4 Overlay landuse and soil maps to calculate the percentage of each land use area and each type of soil on each sub-basin.

2.5 Enter the meteorological and hydrological data files following SWAT's format.

2.6 Select the computation period (the starting and ending time) and evaporation calculating method, whether or not taking into account water quality in rivers and lakes, what kind of output results will be drawn, etc.

2.7 Calibrate model. If the results between simulated and measured datas are not appropriate with together, adjust the parameters of the model.

2.8 Validate model.

2.9 Export calculation results.

3 SWAT Parameters

SWAT is a comprehensive, semi-distributed river basin model that requires a large number of input parameters, which complicates model parameterization and calibration.

3.1 The parameters of surface runoff formation calculation

3.1.1 The parameters calculated effective rainfall

Infiltration SCS Curve Method (1972) of Effective rainfall calculation.

CN2: Initial SCS runoff curve number for moisture condition II (in file * . MGT).

Green & Ampt infiltration method of total flow calculation:

SOL_K: hydraulic conductivity in the saturated case (in file * . Sol)

SOL_BD: land's mass density (mg/m3) (in file * . Sol)

CLAY: % clay (in file *. Sol)

SAND: % sand (in file *. Sol)

3.1.2 Parameters of flood-peak discharge calculation

OV_N: Manning roughness coefficient for surface runoff (in file *. HRU)

CH_N (1): channel roughness coefficient (in file *. Sub)

3.1.3 Parameters of surface-flow lag coefficient calculation

SURLAG: surface runoff lag coefficient (in file *. BSN)

3.1.4 Parameters of losses-along-the-way calculation

CH_K (1): hydraulic conductivity of the channel (in file *. Sub)

3.1.5 Parameters calculated losses due to evaporation

CANMX: The maximum amount of tree canopy storage capacity (in file *. HRU)

ESCO: Soil evaporation compensation factor (in file *. Sub)

3.2 The parameters of ground water calculation

GWQMN: Threshold depth of water in the shallow aquifer required for return flow to occur (mm) (in file *.Gw)

ALPHA_BF: Baseflow alpha factor (days) (in file *.Gw)

REVAPMN: Threshold depth of water in the shallow aquifer for revap to occur (mm) (in file *.Gw)

3.3 The parameters of flow calculation in the channel

CH_N (2): roughness coefficient of the main channel (in file *. Rte)

MSK_X: weight coefficient in Muskingum method (in file *. BSN)

MSK_CO1: coefficient C1 in the Muskingum method (in file *. BSN)

MSK_CO2: coefficient C2 in Muskingum method (in file *. BSN)

CH_K (2): hydraulic conductivity of the main channel (mm / hr) (in file *. BSN)

EVRCH: evaporation correction factor of the main channel (in file *. BSN)

GW_REVAP: Groundwater revap coefficient (in file *.Gw)

ALPHA_BNK: channel bank ratio coefficient (in file *. Rte)

3.4 The parameters of erosion and nutrients transfer calculation

USLE_K: USLE equation soil erodibility (K) factor (in file *.sol)

USLE_C: Cover or management factor (in file *.sol)

USLE_P: USLE equation support practice factor (in file *.sol)

SURLAG: surface runoff lag coefficient (in file *. BSN)

LAT_SED: The amount of sediment in ground flow (in file *. HRU)

NPERCO: permeability coefficient of nitrogen (in file *. BSN)

ERORGN: rate of organic nitrogen supplement (in file *. HRU)

PHOSKD: coefficient of phosphorus division in the soil (in file *. BSN)

LAT_TTIME: Time of flow transmission (days) (in file *. HRU)

SOL_CBN: The organic carbon content in soil (in file *. Sol)

PERCOP: permeability coefficient of pesticides (in file *. BSN)

APPENDIX B

RESULTS OF DISCHARGE AND SEDIMENT YIELD FROM SWAT

1. Discharge

Table 1.1 Monthly discharge at Gia Bay station in the period of 1980-1999 (m^3/s)

Year/Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Average	Flood season	Dry season
1980	31.4	29.3	17.2	14.6	39.2	136.8	413.4	224.7	136.3	69.3	48.4	44.1	100.4	169.9	30.8
1981	34.1	26.2	22.8	80.0	84.3	112.5	143.4	125.0	111.8	90.1	63.8	45.5	78.3	111.2	45.4
1982	37.4	29.6	23.2	40.1	38.2	51.3	95.4	171.0	117.4	90.7	62.6	43.0	66.7	94.0	39.3
1983	38.8	29.7	26.4	27.4	92.3	79.4	317.4	155.2	130.8	88.7	80.2	46.6	92.7	144.0	41.5
1984	38.8	32.6	20.8	21.3	35.8	155.2	100.6	178.7	90.4	93.2	124.5	46.3	78.2	109.0	47.4
1985	43.6	31.4	28.2	26.4	63.4	64.3	49.0	135.1	160.1	73.0	79.4	44.0	66.5	90.8	42.2
1986	33.1	27.5	16.3	89.5	193.2	120.2	284.8	89.9	96.7	59.6	43.2	32.2	90.5	140.7	40.3
1987	28.8	18.6	12.4	14.7	66.5	86.6	63.4	70.6	96.7	73.9	46.1	30.3	50.7	76.3	25.2
1988	25.4	19.8	16.1	9.0	11.9	24.9	59.2	216.3	94.5	46.4	31.2	24.7	48.3	75.5	21.0
1989	20.5	18.3	17.6	20.9	75.4	162.4	148.1	73.7	119.1	55.4	31.8	24.7	64.0	105.7	22.3
1990	26.3	21.9	90.4	58.9	57.8	94.6	172.7	79.6	264.5	71.7	57.6	37.3	86.1	123.5	48.7
1991	31.5	22.3	21.6	11.3	21.7	162.0	162.2	79.2	43.1	63.5	33.7	24.1	56.3	88.6	24.1
1992	21.0	19.4	11.9	6.9	73.7	139.6	234.0	45.3	44.1	26.9	23.8	20.1	55.5	93.9	17.2
1993	16.7	19.0	9.0	8.1	126.6	47.2	115.9	85.2	73.1	35.4	28.2	23.7	49.0	80.6	17.4
1994	18.1	17.3	13.8	7.0	45.4	75.4	190.5	229.4	124.2	90.1	49.9	47.0	75.7	125.8	25.5
1995	38.0	28.7	23.8	18.1	18.5	142.9	152.5	315.0	97.6	58.0	50.2	38.7	81.8	130.8	32.9
1996	31.9	20.2	42.2	18.9	33.2	244.3	231.9	208.6	94.0	66.8	56.1	40.9	90.7	146.5	35.0
1997	35.4	26.0	33.5	65.4	32.5	72.5	244.3	126.2	89.7	61.3	41.1	38.2	72.2	104.4	39.9
1998	28.2	18.7	23.7	33.8	40.1	185.0	139.2	70.3	57.0	32.6	27.0	20.5	56.3	87.4	25.3
1999	20.1	13.0	8.5	13.8	36.1	83.2	74.7	109.3	54.6	56.5	48.6	35.5	46.1	69.1	23.2
Average	**29.9**	**23.5**	**24.0**	**29.3**	**59.3**	**112.0**	**169.6**	**139.4**	**104.8**	**65.1**	**51.4**	**35.4**	**70.3**	**108.4**	**32.2**

Table 1.2 Monthly discharge at Gia Bay station in the period of 2020-2039 (m^3/s)

Year/Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Average	Flood season	Dry season
2020	49.3	43.6	28.2	22.9	53.2	143.9	435.3	235.0	139.6	70.5	50.2	46.0	109.8	179.6	40.0
2021	35.7	27.4	23.4	73.5	82.3	111.4	145.8	124.6	110.9	85.9	62.3	44.4	77.3	110.2	44.5
2022	36.5	28.9	22.5	35.2	35.5	49.1	96.5	171.5	116.5	88.1	61.0	42.3	65.3	92.9	37.7
2023	37.5	28.8	24.5	23.3	88.9	77.4	327.3	155.5	130.2	85.6	78.4	45.3	91.9	144.1	39.6
2024	38.2	31.8	20.1	20.2	32.9	155.0	102.4	178.8	89.0	89.8	122.0	45.1	77.1	108.0	46.2
2025	43.1	30.3	27.7	22.8	60.3	62.0	48.1	136.2	159.4	70.0	78.6	42.7	65.1	89.3	40.8
2026	32.1	26.7	15.6	81.1	191.4	119.6	297.4	89.5	96.0	58.5	42.5	31.6	90.2	142.1	38.3
2027	28.3	18.2	12.1	13.7	61.3	85.0	64.4	70.7	96.5	68.9	44.6	29.1	49.4	74.5	24.3
2028	24.6	19.1	15.5	8.3	11.3	23.1	61.3	218.4	93.9	44.0	30.0	23.9	47.8	75.3	20.2
2029	19.8	18.1	17.0	18.1	72.4	161.8	153.9	72.6	119.2	53.0	30.7	23.7	63.4	105.5	21.2
2030	25.5	21.3	84.5	55.4	54.1	93.2	179.7	79.3	264.6	68.5	56.1	36.3	84.9	123.2	46.5
2031	30.7	21.6	20.9	10.5	20.2	160.8	171.9	79.0	41.4	60.7	33.0	23.8	56.2	89.0	23.4
2032	20.4	18.8	11.4	6.3	69.7	140.9	247.5	43.5	42.9	26.1	23.3	20.1	55.9	95.1	16.7
2033	16.4	19.3	8.9	7.6	123.9	45.8	122.5	85.0	71.7	34.1	27.6	23.3	48.8	80.5	17.2
2034	17.7	17.1	13.3	6.4	42.2	75.4	206.5	233.8	125.0	87.5	49.4	47.7	76.8	128.4	25.3
2035	37.7	28.3	23.8	16.9	17.7	142.1	163.6	325.6	97.3	58.1	50.2	38.7	83.3	134.1	32.6
2036	31.8	19.9	39.9	17.4	32.1	246.1	249.5	213.5	94.3	65.5	55.9	40.8	92.2	150.2	34.3
2037	34.6	25.8	31.0	58.2	29.6	69.9	264.3	127.7	89.6	59.2	40.3	37.9	72.3	106.7	38.0
2038	27.5	18.4	23.0	29.5	37.1	188.0	146.9	70.3	56.3	31.7	26.4	20.1	56.3	88.4	24.2
2039	19.5	12.4	8.5	12.6	32.0	82.7	79.3	110.0	53.2	52.1	47.0	33.8	45.2	68.2	22.3
Average	**30.3**	**23.8**	**23.6**	**27.0**	**57.4**	**111.7**	**178.2**	**141.0**	**104.4**	**62.9**	**50.5**	**34.8**	**70.5**	**109.3**	**31.7**

Table 1.3 Monthly discharge at Gia Bay station in the period of 2040-2059 (m^3/s)

Year/Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Annual Average**	**Flood season**	**Dry season**
2040	24.2	22.8	12.2	11.7	46.6	138.2	447.5	231.3	137.2	67.9	48.2	44.3	102.7	178.1	27.2
2041	34.0	25.9	22.2	68.3	81.5	110.5	151.9	126.6	111.3	84.3	62.4	44.3	76.9	111.0	42.9
2042	36.2	28.7	22.5	32.3	34.4	49.0	102.9	174.7	117.4	87.3	61.3	42.6	65.8	94.3	37.3
2043	36.9	28.6	23.8	21.4	87.8	77.1	346.1	158.4	131.0	82.6	78.5	44.9	93.1	147.2	39.0
2044	37.7	31.6	19.9	19.7	32.2	156.5	107.1	182.5	89.8	88.8	124.1	45.1	77.9	109.5	46.3
2045	43.1	30.2	27.6	21.4	59.8	61.8	50.3	139.4	160.9	68.7	79.2	42.7	65.4	90.1	40.7
2046	31.9	26.5	15.4	75.7	191.6	119.9	311.8	90.8	97.3	58.7	42.8	31.6	91.2	145.0	37.3
2047	28.0	18.1	12.1	13.5	58.4	85.0	69.6	72.2	98.2	67.5	44.6	29.2	49.7	75.1	24.2
2048	24.5	18.9	15.7	8.1	11.3	22.8	65.5	225.1	95.2	44.1	30.4	24.1	48.8	77.3	20.3
2049	19.8	17.9	16.9	16.5	71.7	162.1	161.8	74.2	120.4	52.5	31.0	23.7	64.0	107.1	21.0
2050	25.3	21.4	79.9	53.5	52.7	93.5	187.5	80.1	267.9	66.5	56.2	36.1	85.0	124.7	45.4
2051	30.4	21.3	20.7	10.3	19.5	161.8	179.9	80.4	41.6	59.4	33.4	23.9	56.9	90.4	23.3
2052	20.2	18.8	11.1	6.1	67.8	143.1	259.1	43.8	43.1	26.0	23.4	20.5	56.9	97.1	16.7
2053	16.3	19.6	9.0	7.6	122.8	46.2	128.5	86.8	72.6	34.1	28.0	23.6	49.6	81.8	17.4
2054	17.8	17.2	13.2	6.3	40.8	76.2	215.6	238.8	126.2	86.4	49.5	48.5	78.0	130.7	25.4
2055	37.6	28.5	23.7	16.8	17.1	143.1	172.0	333.9	98.5	58.3	50.7	39.0	84.9	137.2	32.7
2056	31.9	19.8	38.6	17.1	31.3	248.3	260.9	217.4	95.2	65.2	56.3	40.9	93.6	153.0	34.1
2057	34.3	25.7	29.5	54.4	27.8	69.7	276.8	130.0	90.2	58.1	40.3	38.0	72.9	108.8	37.0
2058	27.6	17.8	22.6	27.7	35.8	190.4	152.2	70.8	56.4	31.3	26.5	20.0	56.6	89.5	23.7
2059	19.0	12.4	8.3	12.3	29.8	83.2	83.0	111.9	52.9	49.9	46.6	33.8	45.3	68.4	22.1
Average	**28.8**	**22.6**	**22.2**	**25.0**	**56.0**	**111.9**	**186.5**	**143.5**	**105.2**	**61.9**	**50.7**	**34.8**	**70.8**	**110.8**	**30.7**

Table 1.4 Monthly discharge at Gia Bay station in the period of 2060-2079 (m^3/s)

Year/Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Average	Flood season	Dry season
2060	23.6	22.6	12.0	11.6	45.6	141.1	468.2	235.9	138.7	67.8	48.2	44.4	105.0	182.9	27.1
2061	33.9	25.9	22.1	65.5	80.5	112.0	158.4	128.0	112.0	82.5	62.5	44.0	77.3	112.2	42.3
2062	35.8	28.5	22.5	30.0	33.7	49.2	108.2	178.2	118.8	85.7	61.3	42.9	66.2	95.6	36.8
2063	36.2	28.5	23.4	20.4	85.5	77.5	361.8	161.0	132.8	81.2	78.2	44.6	94.3	150.0	38.5
2064	37.3	31.3	19.8	19.7	30.7	159.0	111.2	185.6	89.3	87.1	125.5	44.7	78.4	110.5	46.4
2065	42.8	30.1	27.4	20.8	58.5	62.5	51.7	141.7	162.5	66.5	79.2	42.1	65.5	90.5	40.4
2066	31.4	26.1	15.4	71.8	191.1	121.4	324.5	91.8	97.9	58.8	42.8	31.3	92.0	147.6	36.5
2067	27.6	17.9	12.1	13.5	56.7	86.1	71.8	73.5	98.7	65.0	44.2	28.6	49.6	75.3	24.0
2068	24.0	18.8	15.5	8.1	11.2	23.4	69.8	229.3	96.2	44.1	30.3	24.0	49.6	79.0	20.1
2069	19.3	18.2	16.7	15.6	70.5	164.1	167.8	74.8	121.3	51.3	30.5	23.2	64.4	108.3	20.6
2070	25.0	21.5	75.8	50.9	50.9	93.4	194.6	79.9	270.3	65.2	55.8	35.5	84.9	125.7	44.1
2071	30.1	21.2	20.4	9.8	18.8	162.3	187.7	80.4	41.1	58.1	33.3	23.7	57.2	91.4	23.1
2072	19.8	18.7	10.8	5.7	65.0	145.6	270.1	43.2	42.6	26.1	23.3	20.4	57.6	98.8	16.5
2073	16.2	20.1	8.9	7.4	121.0	46.5	133.9	87.6	72.8	34.1	28.0	23.3	50.0	82.6	17.3
2074	18.0	17.1	13.0	6.0	39.1	77.0	225.5	241.6	126.5	85.3	48.9	48.7	78.9	132.5	25.3
2075	37.5	28.5	23.4	16.4	16.4	143.0	178.8	339.4	98.6	58.5	50.9	38.8	85.8	139.1	32.6
2076	31.8	19.6	37.4	16.6	30.1	250.8	271.4	219.5	94.9	64.6	56.4	40.6	94.5	155.2	33.7
2077	34.0	25.7	28.3	50.0	26.0	70.1	287.4	130.5	90.1	57.4	39.9	37.7	73.1	110.2	35.9
2078	27.1	17.9	22.0	25.7	34.2	192.4	156.1	70.3	55.9	31.1	26.1	19.5	56.5	90.0	23.1
2079	18.5	12.3	8.1	11.7	27.4	83.6	84.4	111.8	51.4	47.7	45.7	33.3	44.6	67.7	21.6
Average	**28.5**	**22.5**	**21.8**	**23.8**	**54.6**	**113.0**	**194.2**	**145.2**	**105.6**	**60.9**	**50.6**	**34.5**	**71.3**	**112.3**	**30.3**

Table 1.5 Monthly discharge at Gia Bay station in the period of 2080-2099 (m^3/s)

Year/Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Average	Flood season	Dry season
2080	23.2	22.3	11.1	10.7	40.5	141.8	483.9	238.1	138.6	68.0	47.4	44.2	105.8	185.1	26.5
2081	33.7	25.8	21.4	60.0	75.7	110.5	161.5	128.0	112.6	79.5	61.4	43.1	76.1	111.3	40.9
2082	35.1	28.2	21.5	26.9	31.0	46.2	111.7	179.4	117.6	84.2	60.2	42.8	65.4	95.0	35.8
2083	35.4	28.3	22.1	18.4	77.4	76.1	374.5	161.7	132.0	76.6	76.1	43.5	93.5	149.7	37.3
2084	36.3	30.6	18.6	18.7	26.9	159.1	112.3	185.6	88.2	84.7	124.9	44.0	77.5	109.5	45.5
2085	42.2	29.8	26.5	19.4	53.3	61.0	51.5	141.6	162.2	64.2	78.3	41.4	64.3	89.0	39.6
2086	30.8	25.9	14.1	66.1	187.0	120.6	332.2	91.7	97.2	58.0	42.0	31.0	91.4	147.8	35.0
2087	26.9	17.7	11.4	12.9	50.4	83.4	73.6	73.5	97.9	62.6	41.7	27.8	48.3	73.6	23.1
2088	23.3	18.3	14.5	7.8	10.6	21.8	70.3	231.5	96.0	42.2	29.6	23.4	49.1	78.7	19.5
2089	18.9	18.1	15.8	14.1	66.3	162.7	170.5	74.2	121.3	49.6	29.5	22.8	63.6	107.4	19.9
2090	24.6	21.3	71.0	49.6	48.5	93.6	201.5	80.5	274.5	63.7	54.9	35.2	84.9	127.0	42.8
2091	29.8	21.1	19.7	10.0	17.8	162.0	193.8	81.5	40.7	56.6	33.1	23.8	57.5	92.1	22.9
2092	19.8	18.7	10.5	5.7	62.0	146.2	278.7	43.4	42.4	25.6	23.0	20.6	58.0	99.7	16.4
2093	16.1	20.5	8.7	7.6	119.0	46.1	138.3	89.0	72.5	33.5	27.6	23.2	50.2	83.1	17.3
2094	17.7	17.6	12.6	6.0	36.9	77.0	233.1	244.6	127.4	84.4	48.4	48.9	79.5	133.9	25.2
2095	37.3	28.6	23.0	16.6	15.2	142.0	185.3	345.2	98.6	58.5	50.8	38.8	86.7	140.8	32.5
2096	31.9	19.8	36.0	16.6	28.7	251.2	279.3	222.4	95.3	64.0	56.1	40.5	95.1	156.8	33.5
2097	33.8	25.6	27.4	47.5	23.6	69.0	295.6	132.0	90.6	55.8	39.2	37.4	73.1	111.1	35.2
2098	27.1	17.4	21.4	24.7	32.2	192.7	158.9	71.4	55.6	30.6	25.8	19.3	56.4	90.3	22.6
2099	18.3	12.1	7.7	11.6	25.3	83.4	85.8	113.6	50.4	44.6	44.5	32.7	44.2	67.2	21.1
Average	**28.1**	**22.4**	**20.8**	**22.5**	**51.4**	**112.3**	**199.6**	**146.4**	**105.6**	**59.3**	**49.7**	**34.2**	**71.0**	**112.4**	**29.6**

2. Sediment Yield (Soil Loss)

Table 2.1 Monthly sediment at Gia Bay station in the period of 1980-1999 (tons)

Year/Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Average	Flood season	Dry season
1980	285	2345	1141	1912	14490	61480	200000	79230	37960	4045	1671	1353	405912	66201	1451
1981	878	651	1652	37160	23700	29010	37930	34350	30200	31010	6042	29	232611	31033	7735
1982	1139	1632	1570	10830	14790	20110	27410	43520	45390	25260	9704	933	202288	29413	4301
1983	3644	1844	4480	9661	34340	17670	172300	74490	66720	24020	21690	1847	432706	64923	7194
1984	22	656	225	3184	13400	66950	18180	76520	14830	25260	88250	1213	308690	35857	15592
1985	1010	2078	2816	5151	26170	15980	8185	63560	106400	21350	24930	152	277782	40274	6023
1986	391	517	240	41950	116300	35160	117900	19770	39410	4007	1541	183	377369	55425	7470
1987	1876	319	1174	2278	16500	36910	20880	14020	34510	19580	3682	16	151746	23733	1558
1988	633	1434	438	397	3831	5077	14500	113500	41610	5705	257	13	187395	30704	529
1989	1259	213	2861	3377	19370	60610	64450	17000	87000	12680	386	372	269577	43518	1411
1990	1158	2891	43910	25130	15210	26470	73130	20860	192100	21900	7003	469	430231	58278	13427
1991	697	243	2492	492	8740	67830	70560	15220	3910	37970	4664	1185	214003	34038	1629
1992	1327	2041	1151	461	43910	84090	123700	3032	7138	13	657	1947	269467	43647	1264
1993	779	3258	585	1182	68100	7920	41980	20440	24400	1769	1190	257	171860	27435	1209
1994	330	1952	1882	801	15910	14110	76270	121100	50040	19130	139	5333	306997	49427	1739
1995	1401	1404	1591	2198	4509	45750	57930	161500	10660	2021	2907	22	291893	47062	1587
1996	538	385	20350	571	13230	126100	81870	80690	15200	8220	6915	211	354280	54218	4828
1997	1976	11	8341	20050	5849	19230	100600	46450	21150	8694	508	998	233857	33662	5314
1998	14	280	4347	13350	8927	50370	40000	24390	14110	2483	420	278	158970	23380	3115
1999	794	119	251	2481	12920	25590	19280	40050	7349	12710	5173	3274	129991	19650	2015
Average	**1008**	**1214**	**5075**	**9131**	**24010**	**40821**	**68353**	**53485**	**42504**	**14391**	**9386**	**1004**	**270381**	**40594**	**4470**

Table 2.2 Monthly sediment at Gia Bay station in the period of 2020-2039 (tons)

Year/Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Average	Flood season	Dry season
2020	221	3535	1575	2154	17480	61470	223800	83240	39510	4513	1772	1522	440792	71669	1797
2021	795	706	1638	29230	21920	25820	46200	35210	28690	27650	6079	28	223966	30915	6413
2022	1057	1602	1438	8843	14890	19440	29210	44340	45000	26560	10230	1035	203645	29907	4034
2023	3300	1819	4106	7383	31460	16670	220700	88750	62410	22800	21950	1900	483248	73798	6743
2024	21	713	228	2840	11410	56030	19150	93690	16240	23920	87760	1473	313475	36740	15506
2025	1037	2092	2585	3987	22800	14700	8449	66930	111300	19330	26630	216	280056	40585	6091
2026	393	658	223	38930	109300	35440	132400	23200	40920	4172	1370	290	387296	57572	6977
2027	1678	453	1152	2113	14060	33440	23470	14600	36100	17640	4113	16	148834	23218	1587
2028	559	1592	441	359	3616	4692	16680	129100	41270	5356	353	12	204031	33452	553
2029	1127	211	2599	2682	18470	61540	69090	23900	88540	11410	354	368	280291	45492	1223
2030	905	2888	35650	23180	12840	25850	90850	21830	227200	18700	7015	482	467390	66212	11687
2031	636	233	2296	352	6438	67740	105500	19910	3865	35110	4642	1269	247991	39761	1571
2032	1206	2015	1014	415	35560	78770	121900	3620	7114	12	623	2228	254476	41163	1250
2033	669	3495	669	1071	60760	7544	53220	21440	23950	1755	1229	350	176152	28112	1247
2034	299	1972	1760	709	13150	14340	92440	132600	61080	19420	84	6075	343929	55505	1816
2035	1299	1455	1556	1914	4064	45190	69160	201400	13230	2054	2994	22	344338	55850	1540
2036	406	388	17940	481	11880	126400	95290	98180	15830	7629	7279	276	381979	59202	4462
2037	1648	11	6692	16520	4753	16870	129800	47970	21650	7829	638	1266	255647	38145	4462
2038	14	342	3827	12300	7385	50310	48400	25350	14290	2333	410	293	165253	24678	2864
2039	725	132	242	2279	10700	25700	23790	46270	7822	11030	5242	3740	137673	20885	2060
Average	**900**	**1316**	**4382**	**7887**	**21647**	**39398**	**80975**	**61077**	**45301**	**13461**	**9538**	**1143**	**287023**	**43643**	**4194**

Table 2.3 Monthly sediment at Gia Bay station in the period of 2040-2059 (tons)

Year/Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Average	Flood season	Dry season
2040	197	1934	1103	1909	18070	64860	221900	87440	44200	5095	1715	1569	449992	73594	1404
2041	796	798	1437	28820	22990	25250	49190	37540	32160	26070	6411	28	231490	32200	6382
2042	1110	1584	1503	7922	12530	20490	39590	46210	48720	25970	10180	1087	216896	32252	3898
2043	2803	1889	3710	6166	29070	16370	238600	89560	62030	19580	22260	1948	493986	75868	6463
2044	21	702	213	2750	10440	67200	24670	98680	15740	23160	89930	1269	334775	39982	15814
2045	966	2146	2575	3466	22330	15910	9801	72000	120100	17950	27990	120	295354	43015	6211
2046	306	592	250	35860	106500	35170	159000	23290	42680	4073	1506	304	409531	61786	6470
2047	1502	370	1164	2046	13380	37480	30460	14820	36080	17650	4215	16	159183	24978	1552
2048	449	1604	450	342	3236	4467	20240	140800	39720	5490	339	12	217149	35659	533
2049	1058	301	2636	2298	16120	63800	76340	23780	90140	10910	371	368	288122	46848	1172
2050	838	2877	33550	21870	11970	28030	111100	22380	228000	16910	7186	498	485209	69732	11137
2051	546	224	2266	363	5941	66790	117700	21480	4439	33210	4750	1344	259052	41593	1582
2052	1117	1986	909	388	35230	80260	145700	4507	7531	12	655	2473	280768	45540	1255
2053	633	3657	609	1050	58770	7844	59250	22980	25980	1574	1290	379	184016	29400	1270
2054	266	2031	1726	651	12390	14860	97790	146800	62330	18960	183	6838	364825	58855	1949
2055	1241	1506	1425	1729	3646	48220	78450	212200	12790	1940	2986	22	366155	59541	1485
2056	462	371	16650	478	11050	131800	122300	101900	15010	7397	7181	237	414835	64910	4230
2057	1554	11	5684	14900	4335	18070	156100	51270	22780	7524	650	1359	284237	43347	4026
2058	14	320	3809	10950	6911	51880	56560	26070	14360	2215	428	431	173947	26333	2659
2059	647	150	223	2144	9467	26380	29510	47100	7961	10060	5342	3911	142895	21746	2070
Average	**826**	**1253**	**4095**	**7305**	**20719**	**41257**	**92213**	**64540**	**46638**	**12787**	**9778**	**1211**	**302621**	**46359**	**4078**

Table 2.4 Monthly sediment at Gia Bay station in the period of 2060-2079 (tons)

Year/Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Average	Flood season	Dry season
2060	138	1957	978	1859	16820	64260	250200	92430	50910	4793	1748	1750	487843	79902	1405
2061	666	884	1501	26010	23790	29000	53810	38610	30410	24390	6727	28	235825	33335	5969
2062	933	1619	1275	6661	12610	19700	45560	48030	50190	24470	10680	1303	223031	33427	3745
2063	2613	1878	3542	5346	27110	16790	266100	93600	58950	18490	22400	2009	518828	80173	6298
2064	21	705	227	2780	9881	69070	26850	104800	14780	21990	92340	1702	345145	41229	16296
2065	820	2130	2506	3201	21790	15980	11030	79030	114900	16190	28090	128	295795	43153	6146
2066	261	688	250	32720	108500	38050	166200	25540	42890	4232	1614	221	421166	64235	5959
2067	1388	501	1102	2015	12490	40910	37360	15910	38040	16190	4457	15	170379	26817	1580
2068	450	1537	384	345	3529	4906	22160	150300	44560	5156	397	12	233736	38435	521
2069	941	255	2431	2048	18650	62050	83350	25830	92600	10210	357	404	299127	48782	1073
2070	787	3001	32640	20520	10730	28690	129600	23270	223900	15380	7217	509	496243	71928	10779
2071	354	231	2208	335	5690	71950	130900	22190	4160	31370	4882	1451	275722	44377	1577
2072	1022	2038	806	366	32210	82820	163400	4477	7463	12	714	2700	298028	48397	1274
2073	597	3930	550	993	58050	8046	67170	23530	26040	1715	1335	385	192340	30759	1298
2074	243	2046	1656	621	12260	18040	131200	176400	63180	17870	208	7181	430905	69825	1992
2075	1166	1618	1349	1603	3417	46450	91690	229900	14800	1918	3098	26	397035	64696	1477
2076	360	399	15180	375	10840	134400	148300	107200	15850	6825	7635	391	447756	70569	4057
2077	1489	11	5301	13310	4016	20390	170700	53130	23360	7155	632	1598	301092	46459	3724
2078	13	372	3587	10350	6364	50910	69020	26050	14520	2487	444	411	184528	28225	2530
2079	558	145	225	2016	8501	27460	33850	48430	7806	9238	5232	4257	147718	22548	2072
Average	**741**	**1297**	**3885**	**6674**	**20362**	**42494**	**104923**	**69433**	**46965**	**12004**	**10010**	**1324**	**320112**	**49363**	**3989**

Table 2.5 Monthly sediment at Gia Bay station in the period of 2080-2099 (tons)

Year/Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Average	Flood season	Dry season
2080	121	1953	1000	1612	14590	68240	309200	94830	49900	4694	1715	1879	549734	90242	1380
2081	530	872	1447	22150	22430	31530	74470	38460	34740	22490	6897	27	256042	37353	5320
2082	826	1712	1261	5586	9107	18980	50340	49550	50130	23380	10560	1427	222859	33581	3562
2083	2392	1944	3389	4340	23240	15780	284500	98120	71880	18060	21860	2068	547573	85263	5999
2084	20	730	129	2529	7996	73840	29480	115200	16030	21110	93130	1740	361934	43943	16380
2085	829	2172	2227	2809	18870	16030	11750	76850	125500	15030	27580	199	299845	44005	5969
2086	211	804	173	27850	102800	41410	204400	26330	43920	4087	1680	328	453992	70491	5174
2087	1268	430	1068	1858	10560	34820	42530	16360	38050	16100	4602	14	167660	26403	1540
2088	356	1663	372	317	2819	4672	24960	155900	45620	5100	435	12	242225	39845	526
2089	876	280	2299	1812	19030	62860	99540	25330	93900	9818	346	446	316538	51746	1010
2090	647	3140	28080	19670	10280	28200	139100	23630	259900	14520	6939	505	534610	79272	9830
2091	452	231	2114	316	5390	72880	137200	23360	4133	29400	4708	1487	281670	45394	1551
2092	931	2111	824	353	30140	84620	196400	4629	7722	12	704	2879	331324	53920	1300
2093	558	4098	590	882	56230	8127	90750	24170	27610	1763	1276	424	216477	34775	1305
2094	234	2156	1598	610	12070	19500	150500	169900	65090	17070	193	7625	446546	72355	2069
2095	1028	1640	1369	1572	2761	51940	108100	231200	13910	2010	3086	22	418638	68320	1453
2096	287	379	14400	417	10610	138800	157900	114300	16930	6700	7602	360	468684	74207	3907
2097	1471	11	5061	12140	3365	19090	186300	59540	23080	6622	358	1799	318837	49666	3473
2098	13	366	3383	8990	5754	55170	78870	26820	14470	2378	419	464	197097	30577	2273
2099	488	129	228	1949	7595	29110	36520	52340	7950	8262	5348	4434	154353	23630	2096
Average	**677**	**1341**	**3551**	**5888**	**18782**	**43780**	**120641**	**71341**	**50523**	**11430**	**9972**	**1407**	**339332**	**52749**	**3806**

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